Snowmass2021 - Letter of Interest

IceCube-Gen2: the next generation wide band neutrino observatory

Thematic Areas: (check all that apply □/■)

■ (IF2) Instrumentation Frontier: Photon Detectors
■ (IF10) Instrumentation Frontier: Radio Detection
■ (UF01) Underground Facilities for Cosmic Frontier
■ (UF03) Underground Detectors
■ (NF1) Neutrino oscillations
■ (NF4) Neutrinos from natural sources
■ (NF10) Neutrino detectors
■ (CF7) Cosmic Probes of Fundamental Physics

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Abstract: IceCube, a cubic kilometer scale neutrino detector, was completed in 2011. In the following decade it discovered a cosmic neutrino flux that was large and it established neutrino astronomy as a major component of multimessenger astrophysics, with many significant particle and astrophysics observations. With IceCube-Gen2 we propose a detector of sufficient volume to increase the neutrino collection rate by an order of magnitude, and a sensitivity to point sources at least a factor five larger than that of IceCube. Here we discuss the current status of the envisioned extension.

IceCube, a cubic kilometer scale neutrino detector, was completed in 2011[1]. With IceCube-Gen2 we propose a detector of sufficient volume to increase the neutrino collection rate by an order of magnitude, and a sensitivity to point sources at least a factor five larger than that of IceCube[2;3]. This is possible by optimizing the new deep, optical array for higher energies, where the astrophysical flux is more prominent, and by adding a radio-detection component to Gen2, with sensitivity at energies above 10^{16} eV. In the meantime, an infill-extension of IceCube by 7 densely packed strings, called IceCube Upgrade, is underway[4]. Here we describe the detector concept of IceCube-Gen2, and the evolution of its technology from IceCube generation 1 via the IceCube Upgrade.

The IceCube Upgrade of 7 strings has its own science goals: At GeV energies it dramatically improves on the neutrino physics capabilities of IceCube-DeepCore. At high energies it will increase the sensitivity of IceCube by allowing a high precision calibration of the ice and IceCube[5]. This upgrade will consist of 7 strings deployed in 2022/23 Antarctic field season. The optical sensors (see figure 1) developed and built for that will serve as reference for IceCube-Gen2[6;7]. The Upgrade optical modules will employ continuously digitizing ADCs, which enable real time waveform processing and deadtime-free triggering based on high-level features of the PMT waveforms. The mainboard FPGA will evaluate trigger logic and conduct initial feature extraction. Subsequently, a discrete ARM processor connected to the mainboard FPGA by a high-speed parallel interface will refine the feature extraction and perform data compression. Extracted features and a subset of the compressed raw PMT waveforms will be buffered before being sent to the surface as larger packages every few seconds.

This Upgrade will serve in a number of ways as a valuable stepping stone in gearing up for design, production and installation of the much larger IceCube-Gen2 which is envisioned to follow the Upgrade (complete 2022/23) almost in lock-step, beginning construction as early as 2024.

The conceptual approach of the optical Cherenkov detector of IceCube-Gen2 is the same as in IceCube. A large array of optical sensors using photomultiplier tubes will be immersed in a large volume, about 8 km^3, of extremely transparent Antarctic Ice at the South Pole. The sensors are mounted on 120 additional strings, which will be deployed into boreholes of 2600 m depth. The boreholes are drilled with a hot water drill that typically delivers 3 holes per week. The water-filled holes freeze back within days after drilling, leaving the sensors frozen in and optically coupled to the surrounding ice. The new array will be arranged with, and integrated into, the existing IceCube detector infrastructure. The design goals for IceCube-Gen2 take advantage of the extremely clear ice[8;9], and the observed cosmic neutrino flux that dominates the atmospheric background at energies larger than $\sim$ 100 TeV[10–12]. This allows shifting the energy threshold requirement for muons in IceCube from 300 GeV (for the regularly spaced strings, not including Deep Core) to about 10 TeV. In addition we instrument the strings more densely with sensors that have directional sensitivity[7]. Therefore a string spacing of $\sim$ 240 m, a factor 2 larger than IceCube is possible, leading to a configuration shown in figure 2.

A total of 100 optical sensors are planned on each string. For Gen2 a further gradual evolution of the Upgrade design is in development that contains elements of both modules. In this design concept, Gen2 modules each include 14 to 16 PMTs of 3.5 or 4 inch diameter. The PMT coverage on the strings will be comparable to the Upgrade and a factor of $\sim$2 larger than in IceCube. The diameter of the pressure housing will be smaller than in the Upgrade-mDOM, allowing for smaller boreholes and faster deployment.

The electronics will be optimized for power and modularity. Each PMT will be equipped with a base that generates high voltage and digitizes the PMT signal, which will be connected to a control board. The power and communications infrastructure will be similar to IceCube except for optimizations that result in reduced power and data transmission requirements, including cost savings for cables. The overall design optimization will result in a reduction of cost per unit area of PMT cathode.

Figure 1: Prototypes of an mDOM (left) and an D-Egg (right) for the IceCube Upgrade.

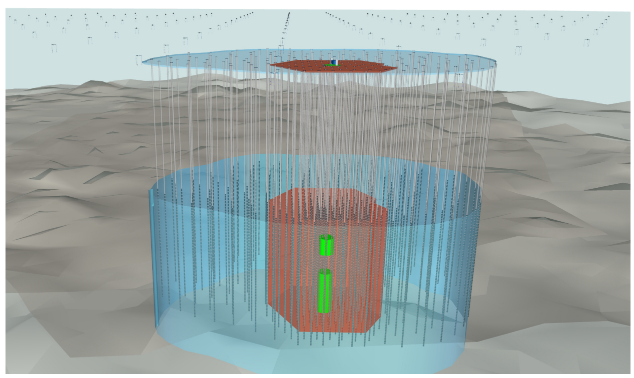

Figure 2: Schematic drawing of the IceCube-Gen2 facility including the optical array (blue shaded region) that contains IceCube (red shaded region) and a densely instrumented core installed in the IceCube Upgrade (green shaded region). The stations of the giant radio array deployed at shallow depths and the surface extend all the way to the horizon in this perspective.

The construction at the South Pole will utilize an advanced version of the hot water drill. Important changes of the drill will include a more simplified and modular design that simplifies operations and transportation on the ice. IceCube-Gen2 strings will be integrated into the IceCube data acquisition after every deployment season. The construction is planned to require 7 – to a maximum of 8 – field seasons at the South Pole.

A large radio array will complement the optical detector array with primary sensitivity above an energy of 10 PeV. The radio array will extend out to more than 10 km distance from the South Pole station and cover an ice volume of order 1000 km^3.

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