Concept Study of a Radio Array Embedded in a Deep Gen2-like Optical Array

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The IceCube Gen2 Collaboration
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Overview

The IceCube Experiment is planning a large expansion called Gen2, including an optical array and a large radio array at shallow depth [1]. Detectors like ARA[4], ARIANNA[5] and RNO-G [6] are well suited for ultra-high energy neutrinos searches. This study explores the potential of co-deploying 9760 ARA style vertically polarized radio antennas, one with each optical sensor, within the planned Gen2-Optical detector strings (between 1350 m and 2600 m deep). Hybrid detection of events in optical and radio could substantially improve the angular resolution of neutrino induced cascades. We show the first results of simulating neutrinos in an energy range from 6 to 100 PeV.

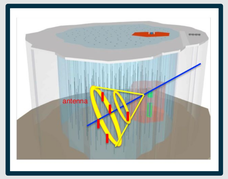

Figure 1: A neutrino event in IceCube-Gen2 detected by the hypothetical radio component

Simulation Setup

The hypothetical radio detector uses vertically polarized radio antennas attached to one channel of every Gen2-Optical DOM. Simulated electron neutrino and electron antineutrino events at 6 PeV, 10 PeV, 30 PeV, and 100 PeV inside of IceCube and the Gen2-Optical volume. Radio simulations are made with PyREx and optical simulations are from Gen2-Optical IceTray package.

Optical

The optical response to a 30PeV electron neutrino undergoing a charged current interaction as simulated by Gen2 IceTray followed by an angular reconstruction with DirectFit[7] using the same ice models.

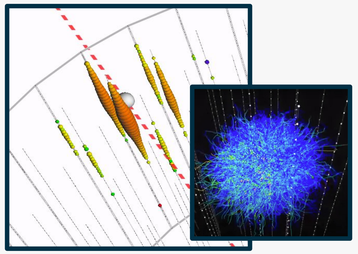

Figure 2: Triggered DOM topology is spherical and localized due to low scattering and attenuation length in optical regime.

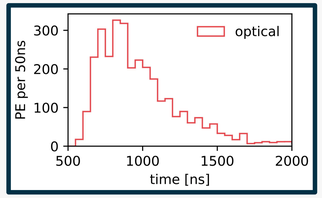

Figure 3: Waveform generated by optical photons in a photomultiplier at a distance of 118 m.
FWHM ~ 500ns.

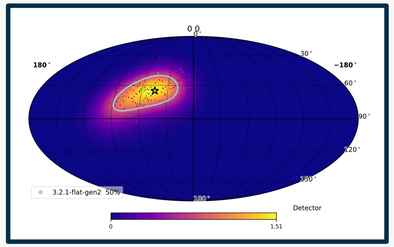

Figure 4: Angular Reconstruction with Optical Data: Resolution ~10°.

Radio

The radio response to the **same event** simulated in the optical section. With the optical reconstruction providing an estimate of the vertex location, and by assuming the brightest antenna per string is exactly on the Cherenkov cone, we can reconstruct the neutrino's direction geometrically.

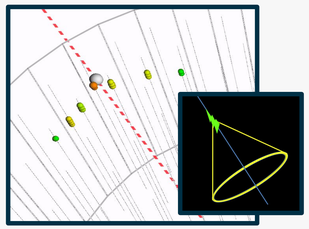

Figure 5: Triggered antenna topology follows Cherenkov Cone and extends to many strings, thanks to long scattering and attenuation length in radio.

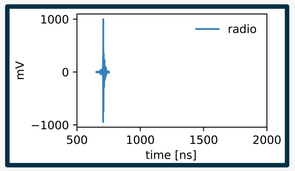

Figure 6: A simulated RF waveforms is shown for an antenna at 118 m distance. Noise of 40 mV is not shown.

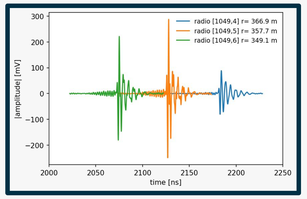

Figure 7: Waveforms from 3 radio antennas on a string further from the event where no DOMs were triggered. Only bright signals could be self triggered.

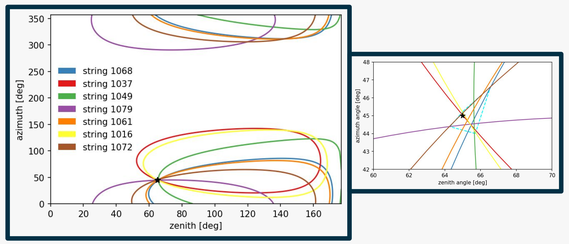

Figure 8: Angular Reconstruction with Optical + Radio Data: Resolution better than ~1°. Plot on the right is an zoomed-in version of the one on the left.

The convex hull (blue, dashed triangle in small figure) shows the estimate for neutrino direction based on estimates from the brightest signal on each triggered string (solid, colored lines). The true location is: zenith=65° and azimuth=45°.

Event Rates

Fig. 9 shows the projected number of events observed in Gen2 based on the best fit IceCube E^-2.49 flux and an effective volume of IceCube-Gen2 = 10 x IceCube, corresponding to the instrumented volume ratio. Table 1 shows the fraction of events with radio signal.

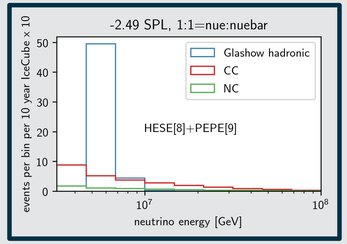

Figure 9: Number of Glashow hadronic, CC and NC from nue/nuebar selected by HESE [8] and PEPE [9] for 10 years IceCube*10 assuming single powerlaw flux E^-2.49.

Energy /PeV	Fraction of Events with Radio Content
6	0.11
10	0.41
30	0.84
100	0.91

Table 1: Fraction of events with radio signals above 2σ on at least 2 antennas.

Summary

This study simulated the optical and radio response of a hypothetical detector with radio antennas connected to every proposed Gen2-Optical DOM. This detector is not proposed for the Gen2 project, this is merely a conceptual study. In a simplistic reconstruction of contained 30 PeV cascade we see radio signals along the Cherenkov cone and obtain a preliminary angular reconstruction within 1° of truth. In the energy range from 6 PeV - 100 PeV, we see a modest handful of events per year yielding radio signals that could be used for event reconstruction. It is still under study if embedded antennas could possibly increase the yield of non contained events pointing towards the detector.

References

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