Future Plans for the ACORNE Collaboration

Lee F. Thompson, on behalf of the ACORNE Collaboration

Department of Physics and Astronomy, University of Sheffield, Sheffield, S3 7RH, England.

l.thompson@sheffield.ac.uk

Abstract. A summary of the future plans for ACORNE collaboration are presented. Of particular note is the intended development of an acoustic calibrator to be deployed in the deep sea above the Rona hydrophone array. Crucial to this goal is work recently completed on the understanding of hydrophone response and the generation of bipolar acoustic signals; this work is presented in detail.

1. Introduction

The ARENA 2006 conference has seen a number of presentations from the ACORNE collaboration on recent results [1-4]. In this presentation we focus on the future plans of the collaboration, in particular with respect to the following subject areas:

• Data collection and analysis from the Rona hydrophone array;
• The design and development of an acoustic calibrator capable of simulating the expected acoustic signal from a UHE neutrino in water;
• The development of a full 3D ultra-high energy neutrino (UHE) simulation code that includes fluctuations.

2. Rona data acquisition and analysis

A data-taking run taken at the Rona hydrophone range over 15 days in December 2005 has yielded 2.8Tb of raw data from the 8 hydrophones which were sampled at 140kHz. Analysis of these data is already underway and was reported elsewhere at this conference [1] and [2]. It should be stressed that this approach to recording raw hydrophone data benefits from a lack of inbuilt bias in the data that other data might have where, for example, only the output from a matched filter is recorded.

The data acquisition paradigm used for the December 2005 run was found to be inefficient – requiring a large RAID disk array to be transported several hundred miles from Rona to Sheffield once full. As a consequence a new system was devised based on an LT03 tape system loaded with 16 LT03 tapes offering a total capacity of 6.4Tb. The collaboration also identified and tested flac a freely available lossless audio compression codec that is both fast and efficient (audio .wav files are reduced to 46% of their original size). This combination of these two features means that unattended data-taking of the full Rona hydrophone array can take place for 60 days. Furthermore data can now be transferred between Rona and Sheffield via tapes and not hard disks.

This new data acquisition system was installed at Rona in September 2006 and has been taking data continuously ever since.
Towards an acoustic calibrator

3.1. Background

Of particular interest to the acoustic detection community is the ability to simulate the signal expected from a UHE neutrino in water. With such a “calibrator” developed it is expected to deploy it above the Rona hydrophone array to study the behaviour of deep-water acoustic sensors to this type of signal.

The most effective way of simulating a UHE neutrino would be to deposit, in a controlled manner, an equivalent amount of energy (typically of the order of 1J for a ~10^{19}eV neutrino), in a comparable volume of water. A number of technologies have been considered (lasers, high intensity LEDs, heating wires, spark gaps) but none have proven capable of producing the required, almost instantaneous energy deposition.

In the absence of an energy calibrator the next option is an acoustic calibrator. Since the relationship between the energy deposition and the corresponding acoustic pulse, as first calculated by Learned [5], is well known then a system capable of producing a bipolar acoustic pulse of known shape and amplitude can be directly related to the parameters of an equivalent neutrino.

3.2. Signal Processing Techniques

In order to develop an acoustic calibrator certain signal processing techniques need to be adopted. For the case of a transmit (Tx) system then an electrical impulse \( y(t) \) is applied to a hydrophone with an impulse response \( h(t) \) to give an acoustic signal \( s(t) \). In the case of a receive (Rx) system the flow is reversed and a received acoustic signal \( s(t) \) when detected on a hydrophone with impulse response \( h(t) \) gives an electrical output \( y(t) \).

In general the following is true:

- If any two of \( s(t) \), \( h(t) \) and \( y(t) \) are known then the other can be calculated;
- (De-)Convolution in the time domain is equivalent to multiplication (division) in the frequency domain;
- Fourier and Inverse Fourier Transforms can be used to transfer between domains (e.g. time to frequency and vice versa).

For any hydrophone therefore it is possible to calculate the electrical impulse signal required for that hydrophone to produce a bipolar acoustic pulse in water by following the following steps:

1. Apply a known acoustic signal \( s(t) \) (e.g. a step function) to the hydrophone with unknown response \( h(t) \);
2. Differentiate the observed output \( y(t) \) from the hydrophone;
3. Take the Fourier Transform (FT) of \( y(t) \) – this corresponds to the response of the system in the frequency domain and includes full phase information;
4. Fit a transfer function to the output of the FT in 3. using a 5th order LRC model which is a suitable equivalent circuit for a hydrophone;
5. Take the desired output acoustic signal \( s(t) \) (i.e. bipolar pulse) and deconvolve it with the now-known hydrophone response \( h(t) \);
6. This yields the required electrical impulse \( y(t) \) required for that particular hydrophone to generate a bipolar pulse.

3.3. The technique in action

The method outlined above has been employed in a lab-based system comprising two wide-band hydrophones and a small (0.6m x 1.5m x 0.6m) water tank. Once steps 1. to 4. in section 3.2 above have been completed a useful cross-check of the technique is to predict the observed output \( y(t) \) to another known input signal \( s(t) \) (for example, a single cycle sine wave) given the hydrophone response \( h(t) \) that has been calculated. This is shown in figure 1 below in which the sine wave impulse (solid line), the predicted response using a 5th order LRC model (dotted line) and the observed response (dashed line) are all depicted.
Of particular note here is the fact that the observed signal bears little resemblance to the initial sine wave impulse signal that was used to excite the hydrophone, in particular the observed signal is quite complicated showing many peaks and troughs which are characteristic of the excitation modes of the hydrophone. However despite the complexity of the observed signal the technique used to determine the hydrophone response does a remarkably good job of predicting the observed output signal. The only significant deviation between the predicted and observed signals occurs after 0.3ms. This does not represent a failing of the technique but corresponds to reflections from the sides of the tank arriving at the receiving hydrophone. This effect is not included in the prediction.

Having completed this cross-check it is now possible to use the technique to generate that electrical impulse signal needed to produce a bipolar pulse from the hydrophone. The results of this operation are shown in figure 2. Here it can be seen that the observed signal, prior to the region affected by reflections, is indeed bipolar in shape. It should be noted that the excitation pulse is not strictly bipolar in shape and, indeed, is significantly more complicated.
Figure 2: Excitation pulse (larger amplitude, in blue) calculated to give a bipolar output for a hydrophone with known response. The actual output is given in green and is seen to be bipolar in nature.

3.4. Determination of the number acoustic transmitters
In addition to successfully simulating the expected pulse shape from a UHE neutrino there are other considerations when designing a neutrino calibrator. The UHE neutrino deposits energy in a cylindrical volume of water that typically has dimensions that are of the order of a few centimetres in radius and typically 10m-20m in length. This leads to a situation where the acoustic signal is expected to lie in a “pancake” perpendicular to the UHE neutrino’s direction. Calculations have shown that in the far field the amplitude of the acoustic signal drops by two orders of magnitude at 5 degrees out of the plane of the pancake. It is clearly desirable therefore that any calibrator mimics this characteristic of the neutrino pulse.

In order to investigate this a study was made whereby a calibrator comprising multiple transmitters was envisaged. These transmitters are spaced equally over a nominal 10m calibrator length, i.e. a 10/n metre spacing for n transmitters. Figure 3 shows the results of this study where the acoustic energy distribution as a function of angle is given for a number of transmitting hydrophones, n = 2, 3, 4, 6, 8, and 10 respectively as viewed in the far field, namely 1km from the neutrino interaction. The study was performed with up to 20 transmitters but very little difference in the angular energy profile can be seen for n>10. It can be seen that fewer than 6 hydrophones do not return the required angular distribution and that ideally something between 6 and 10 transmitters are needed to accurately reproduce a pancake.

4. Simulation work
A paper presented at this conference [3] outlines the work done in adapting the ultra high energy cosmic ray generation code, CORSIKA [6] to work in a water medium and high UHE neutrinos. As reported in [3] work has already started on parameterising the subsequent showers and comparing
those parameterisations with previous work [7],[8]. Once complete, these parameterisations of the energy in the hadronic showers can be used applied to the derive an accurate acoustic pulse in water. This work is ongoing and will be reported in a subsequent paper.

5. Conclusion
This paper outlines the plans of the ACORNE collaboration beyond the 2006 ARENA conference. Data taking at Rona is now proceeding with 8 hydrophones being continuously read out. The design of an acoustic calibrator is underway, it is hoped to deploy this above the Rona hydrophone array in 2007 to study the behaviour of the array to such acoustic signals.

Figure 3: Predicted acoustic energy deposition profile as a function of the angle from the normal to the line array for differing numbers of transmitting elements (n) arranged over 10 metres where n=2 (top-left), 3 (top-right), 4 (middle-left), 6 (middle-right), 8 (bottom-left) and 10 (bottom-right).

6. References
[1] Reconstruction algorithms for ultra-high-energy neutrino events in seawater, S W Bevan, these proceedings
[2] Simulating the sensitivity of hypothetical km$^3$ hydrophone arrays to fluxes of UHE neutrinos, Jonathan Perkin, these proceedings
[3] Simulation of Cosmic Ray $\nu$ Interactions in Water, T Sloan, these proceedings
[4] First Data from ACoRNE and Signal Processing Techniques, Sean Danaher, these proceedings
[5] J G Learned, Phyd. Rev. D 19 (1979) 3293.
[6] CORSIKA: A Monte Carlo Code to Simulate Extensive Air Showers, D. Heck et al., Karlsruhe Report FZKA 6019. (http://www-ik.fzk.de/corsika)
[7] J. Vandenbroucke, G. Gratta, N. Lehtenin, Astrophys. J. 621 (2005) 301
[8] V. Niess and V. Bertin, Astroparticle Physics, 26 (2006) 243