Status of the RICE Experiment

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Abstract

The status of RICE (Radio Ice Čerenkov Experiment, http://kuhep4.phsx.ukans.edu/~iceman/RICE.html), now part of the larger AMANDA effort, is summarized. Attention is focused on recent progress.

1 Introduction

The RICE experiment is philosophically similar to the larger AMANDA effort in that it seeks to measure ultra-high energy (UHE) neutrinos by detection of Čerenkov radiation resulting from the collision of a UHE neutrino with the target ice. Whereas AMANDA is optimized for detection of penetrating muons resulting from $\nu_\mu + N \rightarrow \mu + N'$, RICE seeks to measure electromagnetic cascades initiated by e^+/e^-: $\nu_e + N \rightarrow e^\pm + N'$. As the cascade develops, atomic electrons in the atomic medium are swept into the forward-moving shower, resulting in a net charge on the shower front of $Q_{tot} = 0.25 E_s(GeV)e$.

Such cascades produce broadband Čerenkov radiation – for wavelengths larger than the transverse dimensions of the shower front ($2r_{Moliere}$, or ≈10 cm in ice), the emitting region increasingly approximates a point charge of magnitude Q_{tot}. At these (RF) wavelengths, the net Čerenkov radiation produced by the shower front can therefore be considered coherent (Askaryan, 1962). By contrast, the resultant short wavelength (optical frequency) Čerenkov power is obtained from an incoherent sum over the electric field vectors associated with each short-wavelength Čerenkov wavefront. The experimental sensitivity in the long-wavelength radio regime is further enhanced by the very long attenuation length for cold polar ice ($\lambda_{atten}^{1\,GHz}$ ∼1 km). Although estimates for the threshold vary, it is generally agreed (Price, 1995) that somewhere in the range 1 PeV< E_{ν_e} <10 PeV, detection of a radio wavelength signal offers greater sensitive volume per module than for photomultiplier tubes.

The RICE experiment presently con-

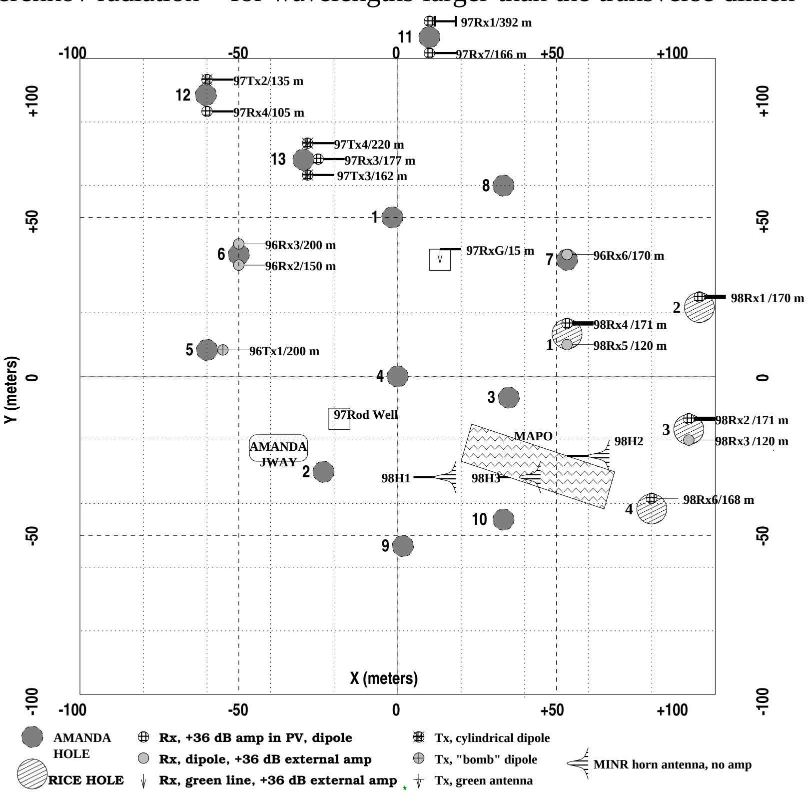

Figure 1: Present geometry of the RICE array, relative to AMANDA hole 4. "Tx" designate transmitters; "Rx" desginate receivers. Depths are also indicated.

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sists of a 16 channel array of radio receivers. Six receivers are buried in the same boreholes as drilled for the AMANDA photomultiplier tube deployment during the 1996-97 and 1997-98 austral summers. Seven receivers are located in dedicated RICE holes; four such holes were drilled with a standard mechanical hole-borer in 1998-99. The present status of the hardware is presented in Figure 1; transmitters ("Tx") are distinguished from receivers ("Rx"). The signal from each antenna is boosted by a 36-dB in-ice amplifier, then carried by coaxial cable to the surface observatory, where the signal is filtered (suppressing noise below 200 MHz), re-amplified, and fed into a CAMAC crate. After initial discrimination (using a LeCroy 3412E discriminator), the signal is routed into a NIM crate where the trigger logic resides. Also deployed this year are three large TEM surface horn antennas which are used as a veto of surface-generated noise.

2 Event Trigger, Calibration and Vertex Reconstruction

A valid event trigger is defined when any one of three criteria is satisfied in a time window of 1 μs: a) $\geq$4 underice antennas register signals above threshold, b) $\geq$ one underice antenna registers a signal above threshold in coincidence with a SPASE trigger, c) $\geq$ one underice antenna registers a signal above threshold in coincidence with a 30-fold PMT AMANDA trigger. To reject background noise, there are two primary ways that events can be vetoed – either: a) one of the surface horn antennas registers a signal in coincidence with any of the above three trigger criteria being satisfied, or b) the timing sequence of hits in the underice antennas is determined to be consistent (in software) with the sequence expected from surface generated backgrounds.

If any of the above trigger criteria are satisfied and there is no veto signal, the time of each hit above threshold (as recorded by LeCroy 3377 TDC), and also an 8 μs buffer of data stored in an HP54542A digital oscilloscope at 1 GSa/s (for each channel) is written to disk. Data is subsequently ftp'ed back to the US for further analysis. As of this writing, the experiment is run remotely from the home institutions in the States during the time when there is a satellite connection to the RICE DAQ PC. At present, raw trigger rates (before veto) are typically 4 Hz; typical data-taking rates after the veto are 0.01 – 0.1 Hz.

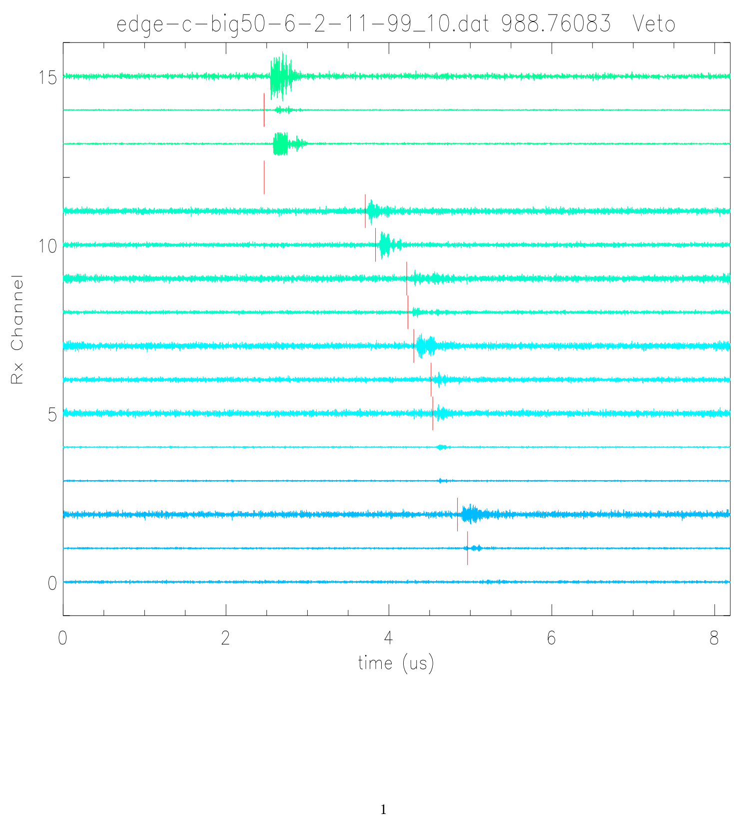

Figure 2: Voltage(t) traces for a typical event. Receiver channels are ordered (from top to bottom) by distance from the surface. Recorded TDC times (|) are superimposed on the digital oscilloscope traces.

Event and source reconstruction is performed by a χ^2 minimization process derived from a knowledge of the relative delays δt_{ij} in the signal arrival times for a given event, in each underice receiver. Given four or more hit antennas (i.e., 3 δt_{ij} values), an event vertex and source direction can be determined numerically. A typical "event" pulse, as recorded in the digital oscilloscopes, is shown in Figure 2. Shown are the oscilloscope traces corresponding to the 15 receiver channels that were connected at the time that these data were taken (Feb. 8, 1999). The arrival of the pulse in each channel is evident from the Figure; since the channels are ordered by their relative distance from the surface observatory, one observes in this event the clear signature of surface-generated noise sweeping down through the array from top to bottom. The characteristic pattern observed in this Figure easily satisfies veto criterion b) as enumerated above (note that we save a selectable fraction of the veto events for future analysis).

Contributions to δt_{ij} come from several sources, including differences in signal propagation velocity in the ice due to variations in the dielectric constant with depth, differences in signal propagation speed within the different analog cables being used, differences in cable lengths, and channel-to-channel jitter within the surface readout and data acquisition electronics.

Buried transmitters are used to calibrate the channel-to-channel timing delays. A 5 ns duration pulse is sent to one of four transmitters, which subsequently broadcasts the signal to the receiver array. An event vertex is reconstructed exclusively from the measured time delays; comparison with the actual transmitter location allows a calculation of the timing residual χ^2 for each channel $(\frac{\delta t_{ij}^{\rm measured}-\delta t_{ij}^{\rm expected}}{\sigma_t})^2$. An iterative procedure is used to calibrate out the observed channel-to-channel timing delays and minimize the timing residuals for an ensemble of events. A calibration event is shown in Figure 3. Here the χ^2 probability is calculated over a 3 dimensional grid (grid size = 20m) of possible vertex points 500 meters on a side. Three orthogonal 2 dimensional slices each passing though the minimum value of χ^2 are shown. The colors indicate probabilities ranging from near zero (black) to near unity (red). Small squares indicate the positions of all RICE receivers (refer to Fig. 1) and the the white diamond indicates the known position of the RICE transmitter 96Tx6 (see Fig. 1) which emitted the reconstructed pulse. In this case the difference between known and reconstructed event vertex is about 13m. The spatial residual, at this very early level of calibration, is typically 10 meters, which is consistent with the intrinsic resolution of our calibration technique (with more CPU, this can be improved to arbitrary precision). Given a receiver-to-receiver spacing of typically 100 meters, the inferred angular resolution is of order 100 mrad. This number is also expected to improve by a factor of 2-3 as the timing calibration is improved over the next few months.

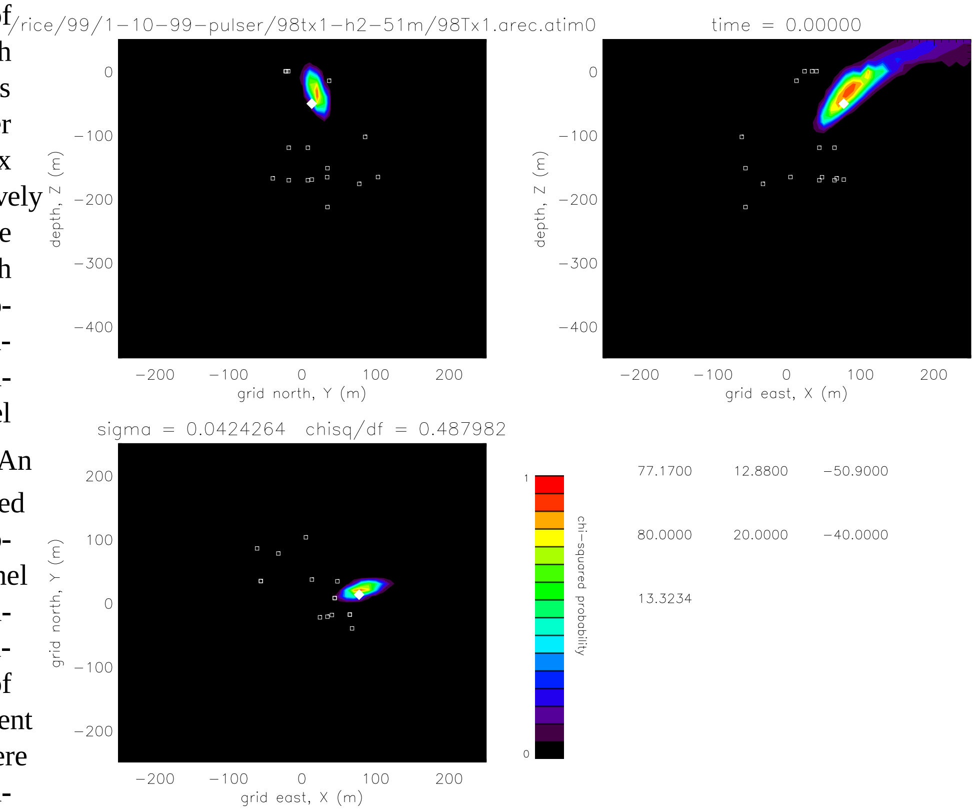

Figure 3: Reconstruction of Tx pulse, based exclusively on measured receiver times. Diamond indicates known location of transmitter; color intensity code indicates χ^2 of reconstruction. Open white squares indicate receivers.

3 Data Analysis Status

Figure 4 shows the distribution of sources recorded by 203 triggers recorded on February 24, 1999. The overwhelming majority of our recorded triggers to date are consistent with surface-generated noise backgrounds (Z≥0); no clear neutrino candidates have been observed. Unfortunately, the signal rate for other physics processes, given the very high energy threshold of the experiment and the relatively small number of receivers deployed to date, is almost negligibly small. (For our current array, we expect to observe less than 0.1 hard bremstrahlung from a UHE muon, e.g., in one year.) Analysis is currently in progress; roughly, every 15 days of livetime corresponds to a sensitivity level comparable to 1% that of current predictions for the incident UHE neutrino flux (Stecker & Salamon, 1995)

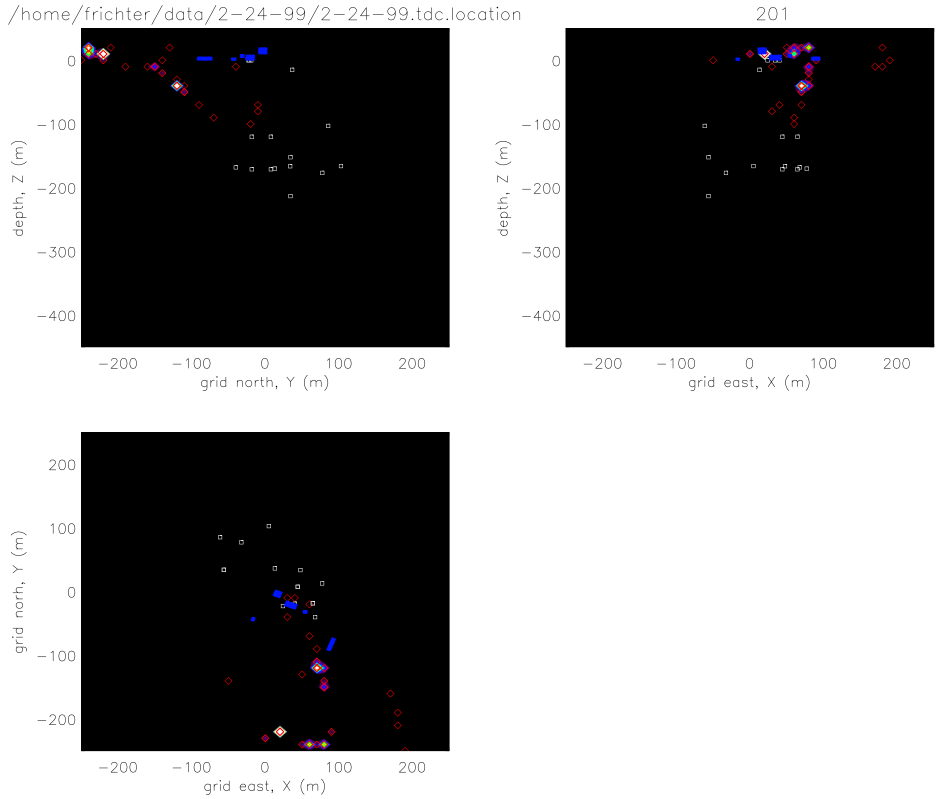

Figure 4: 2/14/99 source (x,y,z) distribution; square=Rx, ⋄=reconstructed vertex location.

4 Future Plans

As of this writing, the RICE experiment is taking data daily with 13 underice receivers and 3 surface horn antennas. Stronger rejection of surface backgrounds (either in hardware or perhaps by implementation of a simple surface wire grid) is the objective of the 1999-2000 austral summer campaign. If one full year of livetime can be accumulated, sensitivity to current predictions for the ultra-high energy neutrino flux will be attained. Further improvement can be achieved by: a) deployment of additional receiver modules, b) improvement of the bandwidth of the antennas (presently we use dipole antennas with ∼200 MHz bandwidth; designs such as bicones can give us ≥500 MHz bandwidth), improvement of signal transmission technology (optical fiber, e.g., over coaxial cable), and, as mentioned previously d) stronger rejection of surface backgrounds. A plan to measure the radio coherence signal in a testbeam is also planned; a background survey conducted at SLAC in May, 1997 by two of us verified that the RF background environment should be sufficiently quiet such that the expected coherent Čerenkov signal should easily be discernable above background.

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