Results from a Study of Acoustic Ultrahigh-energy Neutrino Detection (SAUND)

http://hep.stanford.edu/neutrino/SAUND/

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Stanford University
Workshop on Acoustic Cosmic Ray and Neutrino Detection
Andros Island, The Bahamas
AUTEC hydrophone array
Site 3
Site 3
DAQ system
Calibration sources
21 Events per lightbulb
Light bulb positions and energies reconstructed
Light bulb positions and energies reconstructed
Detection contours under typical noise conditions

Detection volume contours, from $5\times10^{20}$ eV to $3\times10^{21}$ eV, contour interval $5\times10^{20}$ eV
Detection contours under typical noise conditions (zoomed in)
Pancakes can be good
AUTEC SVP

AUTEC sound velocity profile

Depth (m)

Speed (m/s)
Refraction is significant beyond 1 km
Refraction is significant beyond 1 km

Ray trace with source at 1600 m depth, for initial angle 0-30 degrees from horizontal
Refracted pancake (undetected)
300 m deflection!

Refracted acoustic radiation disk cross section for a $10^{21}$ eV neutrino at zenith 0 deg
Refracted pancake (detected)
100 m deflection

Refracted acoustic radiation disk cross section for a 1e+21 eV neutrino at zenith 0.5 deg
Localization achieved
Localization $\rightarrow$ energy reconstruction
Cut 1: Digital Filter

\[ \text{signal} : S(t) \propto -\frac{t}{\tau} e^{-t^2/2\tau^2} \]

\[ \text{noise} : N(t) \propto f^{-2} \]

\[ \rightarrow \text{response function} : H(t) \propto -\left( \left( \frac{t}{\tau} \right)^3 - 3 \frac{t}{\tau} \right) e^{-t^2/2\tau^2} \]

\[ \tau = 10 \mu s \]
Cut 3: Five-phone coincidence

Require

1) Events obey causality:
   Pairwise, times are within coincidence window: \( t_{ij} < c * d_{ij} \)

2) Geometry consistent with pancake (2D circle) shape:

   accepted:
   
   rejected:
Example of a five-phone event
Example of a five-phone event

![Graph showing five phone events](image-url)
Cuts 4a and 4b: Characteristic Frequency and Number of Periods
Cut 4c: Diamond Events

frequent but easily rejected with a matched filter (online?)
Examples of dolphin signals recorded by AUTEC personnel
Cut 5: Adaptive threshold
Cut 6: Pancake shape constrains effective volume
(bad news and good news)
Cut 7: Threshold crossings

2 threshold crossings, 4 samples above threshold (hour 2001.12.22.12, event 7136)
# Background rejection

<table>
<thead>
<tr>
<th>Cut</th>
<th>Events passing cut</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Run II, 163 days integrated livetime)</td>
<td></td>
</tr>
<tr>
<td>1) Filter trigger</td>
<td>40 million</td>
</tr>
<tr>
<td>2) Electronic noise</td>
<td>25 million</td>
</tr>
<tr>
<td>3) 5-phone coincidence</td>
<td>5 million</td>
</tr>
<tr>
<td>4) Waveform analysis</td>
<td>3 thousand</td>
</tr>
<tr>
<td>a) Periods &lt; 4</td>
<td></td>
</tr>
<tr>
<td>b) 20 kHz &lt; freq &lt; 40 kHz</td>
<td></td>
</tr>
<tr>
<td>c) Diamond metric &lt; 0.7</td>
<td></td>
</tr>
<tr>
<td>5) Threshold &lt;= 0.024</td>
<td></td>
</tr>
<tr>
<td>6) 5-phone localization</td>
<td>300</td>
</tr>
<tr>
<td>7) Threshold crossings &lt; 2</td>
<td>0</td>
</tr>
</tbody>
</table>

(online, offline)
What have we learned?

- Refraction cannot be neglected for $> \sim 1$ km rays
  - Travel times are not significantly affected, but
  - Arrival direction and radiation envelope are (deflection)
  - Phones on sea floor are bad
  - Ray tracing necessary for localization

- $c_{\text{sound}} = c_{\text{light}} / 200,000$ !!
  - Coincidence is a very weak requirement $\rightarrow$ combinatorics

- 3D localization demonstrated
  - 10 m resolution attained
  - Array geometry important; planar array is worst case
    (but our signal is planar...)
  - Pancake shape a powerful requirement (despite decreased volume)

- Impulsive backgrounds at $10^{21}$ eV exist but can be rejected

- Energy threshold is very high ($10^{21}$ eV) with 1.5 km spacing and current triggers
Whats next?

Analysis
- Rigorous Monte Carlo efficiency check
- Final flux limits

SAUND-II
- More phones, more volume, more computer processing
- Improve adaptive threshold algorithm
- Build coincidences online
- Optimize cut strategy
- Lower energy threshold (one order of magnitude reasonable)
- Push to the Gaussian noise floor

Beyond (other arrays)
- 100-500 m spacing?
- better geometry?
- better noise environment?