Status and Recent Results of the Acoustic Neutrino Detection Test System AMADEUS of ANTARES

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Outline

● Introduction: Acoustic Neutrino Detection and AMADEUS
● Ambient Noise and Transient Background Investigations
● Lessons Learned
● Conclusions and Outlook
Acoustic Detection of Neutrinos

Thermo-acoustic effect: (Askariyan 1979)
energy deposition $\Rightarrow$ local heating ($\sim\mu$K) $\Rightarrow$ expansion $\Rightarrow$ pressure signal

Hadronic cascade:
$\sim$10m length, few cm radius

Pressure field:
Characteristic “pancake” pattern
Long attenuation length ($\sim$5 km @ 10 kHz)
The AMADEUS System of the ANTARES Detector

ANTARES site:
• 2500m depth, 30km offshore

AMADEUS:
• Total of 6 “acoustic storeys”
• Total of 36 hydrophones
• Continuous sampling
• Online filter selects ~1% of data volume for storage
Operation of AMADEUS

- Main objective: feasibility study for a potential future large-scale acoustic neutrino detector
  - Investigate background conditions
  - Determine energy threshold for neutrino detection
  - Devise high efficiency, high purity neutrino detection algorithms
- Data from first line with acoustic sensors: Dec 2007
  Data from two lines:  Nov. 2009 – Oct. 2010
  Since April 2013 (new position of IL)
ANTARES: New Geometry since April 2013

“Instrumentation Line” was redeployed at new position:

- Distance between lines with acoustic storeys:
  - 220m
  - 150m
Background for Acoustic Detection in the Sea

**Ambient noise**

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<th>Frequency [kHz]</th>
<th>Power level [dB re 1(\mu)Pa²/Hz]</th>
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**Transient background**

- **Signal (a.u.), schematic**
- **Bipolar Pressure Signals (BIPs)**

- **Determines intrinsic energy threshold**
  - Use “effective volume” for estimate
  - Depends on “sea state” (surface agitation)
  - (see talk by Dominik Kiessling)

- **Determines fake neutrino rate**
  - Suppress by
    - clustering
    - signal classification
    - fiducial volume cuts

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Transient Background: Properties

• Very diverse
  Shipping traffic, marine mammals, …
  ⇒ perform signal classification

• Mostly originating from near surface
  ⇒ “straight forward” approach:
    Impose cut based on source location

"quiet zone"
Transient Background: Position Reconstruction

- For events selected by online filter, reconstruct direction for individual storeys.
- When directions reconstructed by more than one storey get source location.

Data:
156 days of measuring time from Nov. 2009 to Oct. 2010.
Source Localization

Problem:
Small size of AMADEUS device
⇒ large errors in \( z \), despite good angular resolution for direction reconstruction:
\[ \Delta \theta = 0.6 \pm 0.2^\circ \text{ in zenith} \]
\[ \Delta \phi = 1.6 \pm 0.2^\circ \text{ in azimuth} \]

Solution:
Project positions to sea surface and remove event clusters from moving sound emitters
Cluster Analysis of Moving Sound Emitting Objects
Signal Classification with Machine Learning Algorithms

- Classification:
  - neutrino candidate (BIP) ↔ background

- Different algorithms have been investigated:
  - Random Forest
  - Boosted Trees
  - Naïve Bayes
  - Decision Tree
  - Support Vector Machine

- Recognition Error:
  - For individual sensors < 10%
  - For clusters of sensors < 2%
Spatial Distribution of Transient Background

After signal classification and cluster analysis:

- 100 km$^{-3}$ year$^{-1}$

All reconstructed events:

- $15 \cdot 10^3$ km$^{-3}$ year$^{-1}$
Search for a Fiducial Volume - Motivation

- Using signal classification and cluster analysis for the identification of neutrino-like bipolar signals
- Remaining events density: $\sim 100$ events/km$^3$/yr
- Need for further reduction $\Rightarrow$ cut on the volume
Search for a Fiducial Volume - PSF

Optimize fiducial volume for minimal background content:

- Point spread function calculated from MC Simulations
- Deconvolution of the PSF using Richardson-Lucy-Algorithm
Search for a Fiducial Volume - Cut Strategy

- Optimization problem:
  - Minimal number of events and
  - Maximal remaining volume after applying the cut
- Using a Genetic Algorithm to solve the optimization problem
- Remaining event density after cut: ~0.05 events/km$^3$/yr (but volume closest to sensors is removed)
Further Reduction of Transient Background

Search for characteristic geometry of pressure field from neutrino interaction (“pancake”)

- AMADEUS too small, “2D-geometry”
- investigations with Monte Carlo simulations (input from AMADEUS)
- KM3NeT: Combined system for acoustic positioning and neutrino detection planned ⇒ test bed for algorithm development

See talk by Dominik Kiessling
Effective Volume

\[ V_{\text{eff}} = \frac{\sum p(E, x, e_p) \delta_{\text{sel}}}{N_{\text{gen}}} V_{\text{gen}} \]

- Effective Volume
- Probability of the neutrino reaching the vertex
- Only counted if signal is detected
- Number of Neutrinos: $10^7$
- Volume in which the Neutrinos are generated: 1200 km$^3$

Earth density model (PREM)

Earth

Water

10°
AMADEUS Effective Volume

Level 1:
- low ambient noise
- minimal filter

Level 2:
- noise model (annual distr.)
- std. filter

Preliminary
AMADEUS: Lessons Learned

- Ambient background:
  GZK neutrinos (for pure proton flux) detectable, reduction of threshold crucial \( \Rightarrow \) bigger detector, use signals from more sensors

- Transient noise:
  High level of background (mainly dolphins);
  High level of reduction already achieved with AMADEUS, for competitive flux limits recognition of “acoustic pancake” crucial

- Road ahead:
  Apply knowledge about ambient noise and transient background data to simulations:
    - KM3NeT acoustic system for positioning/neutrino detection
    - large scale fiber-based acoustic neutrino telescope? (see talk on behalf of E.J. Buis)
Conclusions and Outlook

• Ambient noise: Smaller effect on neutrino detection than assumed
• Transient background: Strong suppression achieved, further reduction requires larger detectors
• Monte Carlo simulations developed and energy threshold derived from effective volume of AMADEUS
• Next step KM3NeT: Combined system for acoustic positioning and neutrino detection planned
Thank you for your attention