Acoustic neutrino detection investigations within ANTARES and prospects for KM3NeT

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Outline

- Introduction: acoustic neutrino detection
- Lessons learned from AMADEUS
- Acoustics with KM3NeT
- Summary and conclusions
Acoustic detection of neutrinos

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

Hadronic cascade:
~10m length, few cm radius

Pressure field:
Characteristic “pancake” pattern
Long attenuation length (~5 km @ 10 kHz)

Bipolar Pressure Signal (BIP)

$10^{11}$ GeV @ 1000m

Time [ms]

Pressure [Pa]
The AMADEUS system of the ANTARES detector

ANTARES site:
- 2500m depth, 30km offshore

AMADEUS acoustic neutrino detection test system:
- Total of 6 “acoustic storeys”
- Total of 36 hydrophones
- Continuous sampling
- Online filter selects ~1% of data volume for storage
Background for acoustic detection in the sea

Ambient noise

- **Power level [dB re 1\( \mu \text{Pa}^2/\text{Hz} \)]**
- **Frequency [kHz]**
- **Sea state 0**
- **Sea state 2**
- **Sea state 4**
- **Model ss0**
- **Model ss2**
- **Model ss4**

Transient background

- **Bipolar Pressure Signals (BIPs)**

\( \Rightarrow \text{Determines intrinsic energy threshold} \)

- **Determines fake neutrino rate**

\( \Rightarrow \text{Supress by} \)

- clustering
- signal classification
- fiducial volume cuts

\( \Rightarrow \text{Determines intrinsic energy threshold} \)

- Depends on “sea state” (surface agitation)
Ambient noise – occurrence distribution

Main source: Surface agitation and precipitation

Data of 2008-2010

$\langle \sigma_{\text{noise}} \rangle$ is about 10 mPa (10-50 kHz) and 95% of the time below $2 \langle \sigma_{\text{noise}} \rangle$
Transient background

- Sources: Very diverse; Shipping traffic, marine mammals, ...
  ⇒ Mostly originating from near surface
- Suppression:
  - signal classification
  - Project reconstructed signals to surface, perform clustering
Cluster analysis of moving sound emitting objects
Spatial distribution of transient background

All reconstructed events
0.3 Hz

After signal classification
and cluster analysis
0.002 Hz
AMADEUS: lessons learned

- Ambient background:
  Background low and stable, reduction of SNR for signal detection crucial

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

- Current investigations:
  Apply knowledge about ambient noise and transient background data to simulations of KM3NeT
KM3NeT design

piezo sensor integrated into OM

"South Pole"
Acoustics in KM3NeT

- Acoustics with positioning system “for free”
- Acoustic neutrino detection part of long-term KM3NeT strategy
- In the long run: optical hydrophones (see talk by E.-J. Buis)
- Great interest in acoustic sensing from marine scientists

The crucial questions for acoustic neutrino detection:
- Can we classify neutrinos background-free?
- Energy threshold?
- What volume do we need?
Simulated events

- Neutrinos (Energy $10^{19} - 10^{21}$ eV)
- Signals from the positioning system
- Spherical sources
- Random coincidences

Preliminary results: Select “flat topology” of event
Transient background $4 \times 10^{-7}$ Hz per ARCA-block
(Further reduction needed!)
Simulation: “Transient free limit setting potential“

- AMADEUS
- KM3NeT-Phase 1
- KM3NeT Building Block
- Flux models (Kotera 2010)

EΦ [cm²·s⁻¹·sr⁻¹]

energy threshold

for one your of data taking

size, geometry, time

log(E/GeV)
Conclusions and outlook

- First generation acoustic arrays such as AMADEUS have been used to investigate neutrino detection methods and provide input for simulations
- KM3NeT provides an excellent framework for a second generation acoustic detection test setup “for free” – all software tools exist
- New concepts (fiber based hydrophones) can eventually lead to a “real” acoustic neutrino detector
Thank you for your attention!
Backups
KM3NeT Phase 1 compared to AMDAEUS

AMADEUS
- 2 lines, 230m apart
- 3 floors/line, 14.5 – 100m
  - 6 hydrophones/floor

KM3NeT Phase 1
- 24 lines, 100m apart
- 18 optical modules/line, 36m
  - 1 acoustic sensor/module

Comparing apples and oranges:
- 2D setup vs. 3D setup
- Different number of sensors per cluster
Effective volume for acoustic detection

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

Noise: 15 mPa
Min. SNR: >2
Min. #Sensors: 6
Cosmogenic neutrinos

“GZK neutrinos” produced in interactions of CRs at highest energies with CMB photons

\[ p + p(\gamma) \rightarrow \pi + X \]

\[ \mu + \nu_\mu \]

\[ e + \nu_e + \nu_\mu \]

for GZK \( \nu \): \( >100 \text{km}^2 \cdot 2\pi \cdot \text{year} \) detector needed
Neutrino signatures in different media

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sensor density

- O(100)/km³
- O(10)/km³
- O(1000)/km³

radio lobe

optical light cone

sound disk

adapted from: R. Nahnhauer, ARENA Conf. 2010

10^{16} eV  10^{17} eV  10^{18} eV
Positioning in deep sea Cherenkov neutrino telescopes

Movement of optical modules with deep sea currents needs to be monitored.

Deep sea neutrino telescopes contain acoustic sensors for position calibration.
Source Localization

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

Solution:
Project positions to sea surface and remove event clusters from moving sound emitters
Sound in water

“Of all the forms of radiation known, sound travels through the sea the best”

Used by marine animals and humans for communication and positioning

Speed of sound investigated (at least) since 1826 (from title page of “Physics Today”, Oct. 2004, experiment in Lake Geneva)