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

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Outline

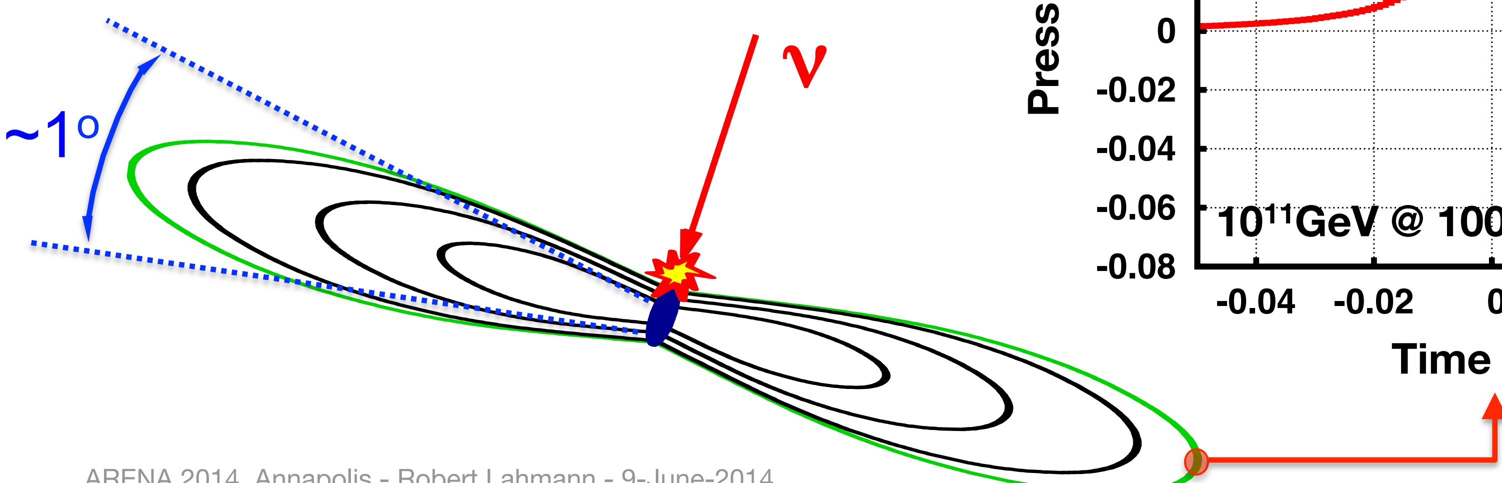
- Introduction: Acoustic Neutrino Detection and AMADEUS
- Ambient Noise and Transient Background Investigations
- Lessons Learned
- Conclusions and Outlook

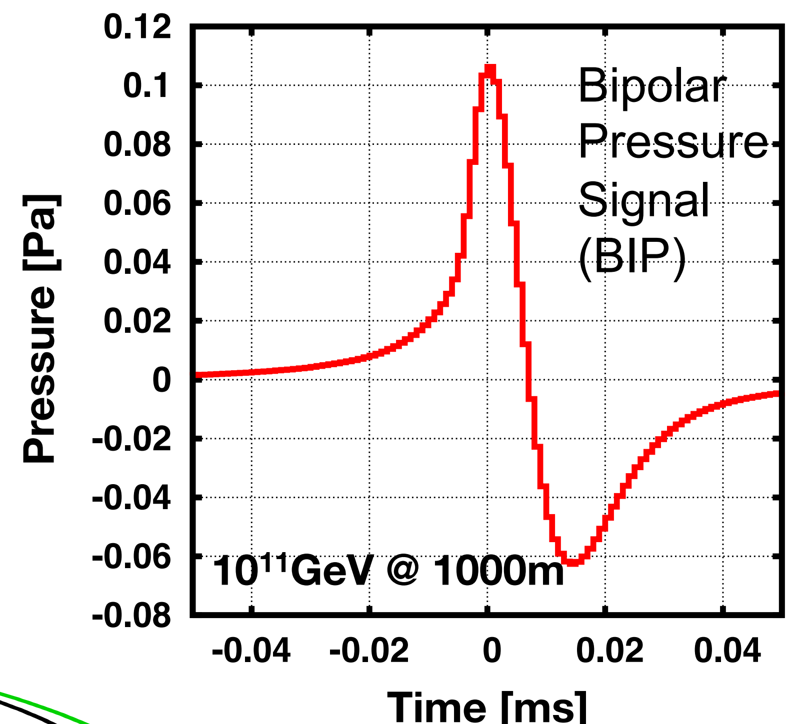
Acoustic Detection of Neutrinos

Thermo-acoustic effect: (Askariyan 1979)
energy deposition ⇨ local heating (~μK) ⇨ expansion ⇨ pressure signal

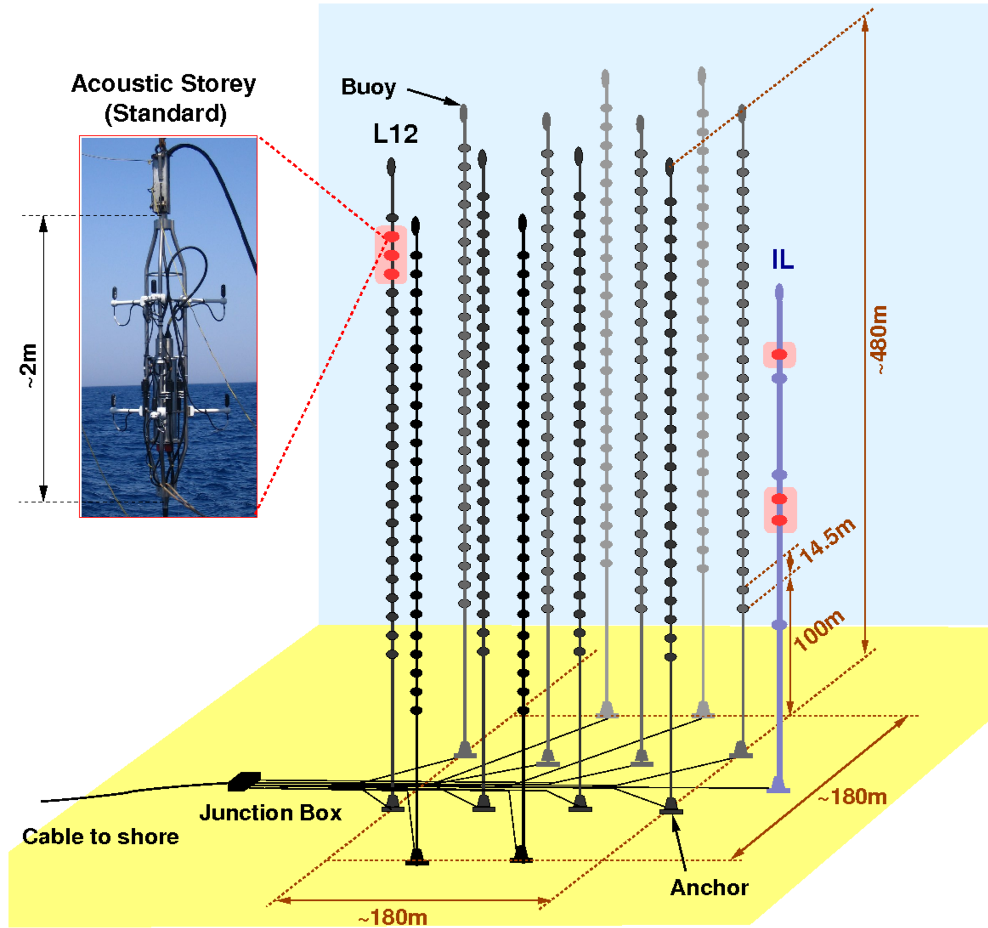
Hadronic cascade:
~10m length, few cm radius

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





The AMADEUS System of the ANTARES Detector



ANTARES site:
- 2500m depth, 30km offshore

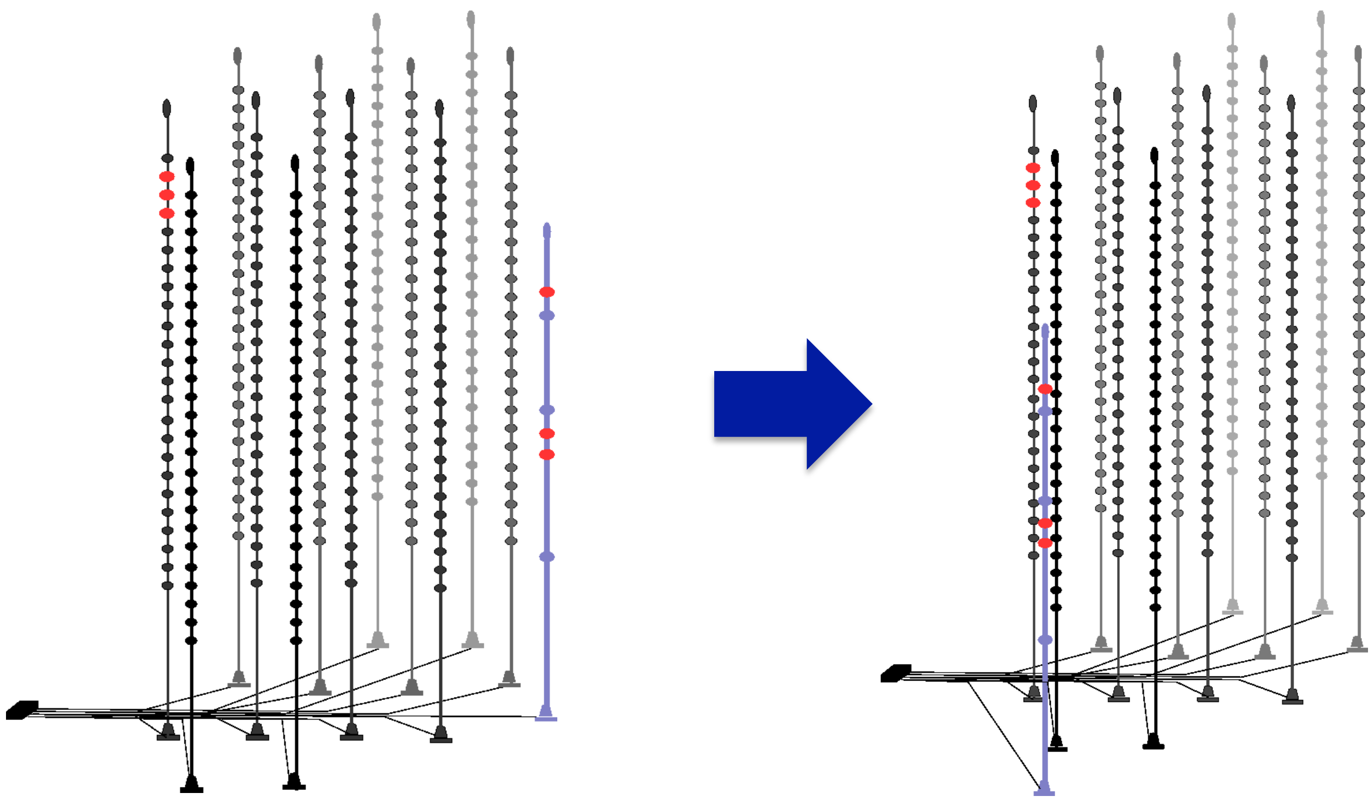
AMADEUS :
- Total of 6 "acoustic storeys"
- Total of 36 hydrophones
- Continuous sampling
- Online filter selects ~1% of data volume for storage

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

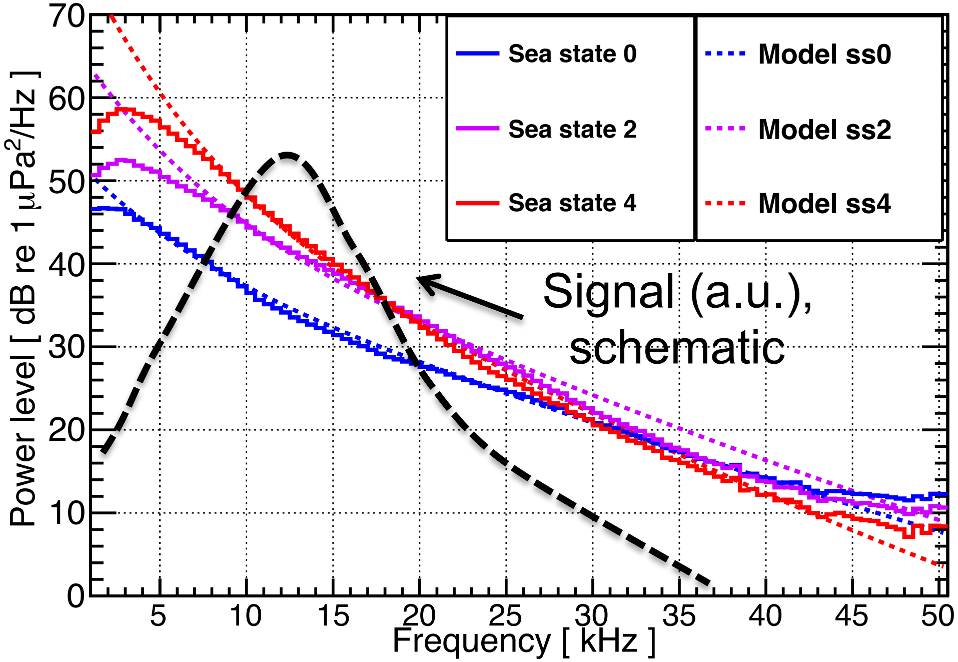
"Instrumentation Line" was redeployed at new position:



220m ⇦ Distance between lines with acoustic storeys ⇨ 150m

Background for Acoustic Detection in the Sea

Ambient noise

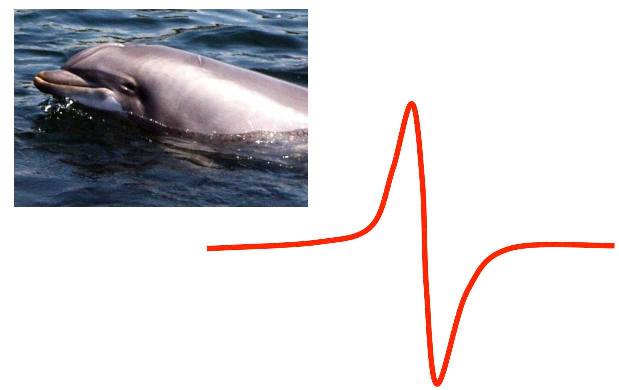


⇨**Determines intrinsic energy threshold**
Use "effective volume" for estimate

Depends on "sea state" (surface agitation)

(see talk by Dominik Kiessling)

Transient background



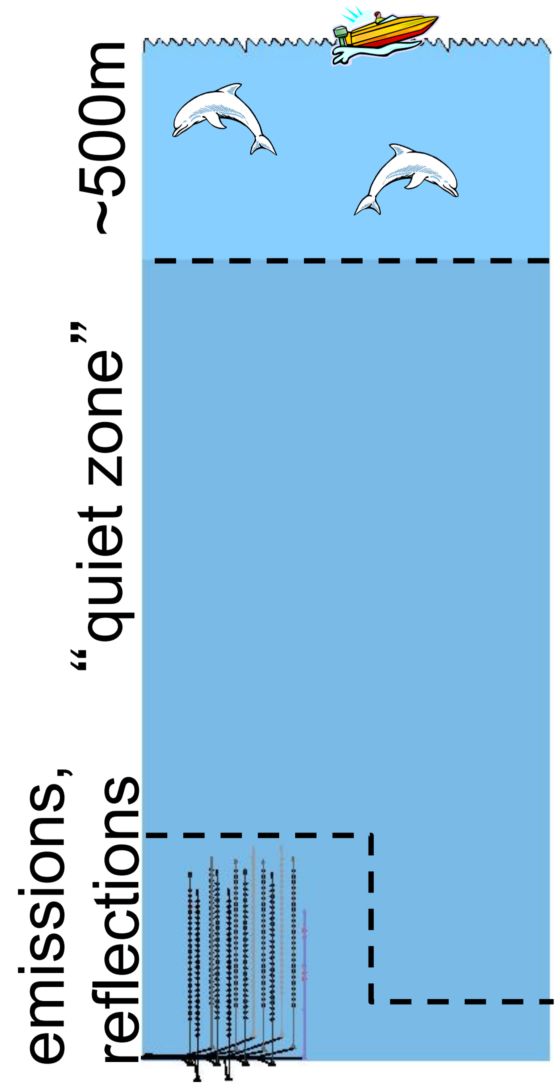
Bipolar Pressure Signals (BIPs)

⇨**Determines fake neutrino rate**

Suppress by
- clustering
- signal classification
- fiducial volume cuts

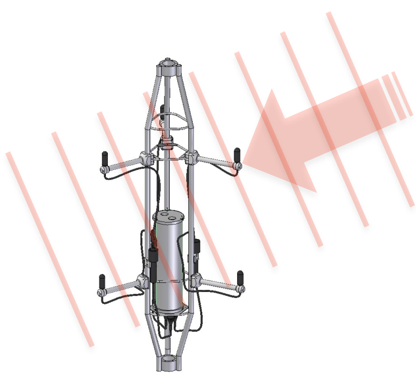
Transient Background: Properties

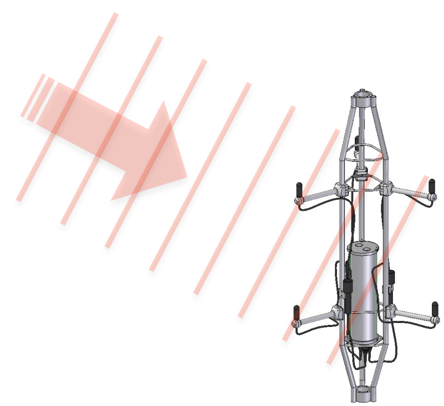
- Very diverse
  Shipping traffic, marine mammals, …
  ⇨ perform signal classification
- Mostly originating from near surface
  ⇨ "straight forward" approach:
  Impose cut based on source location



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:

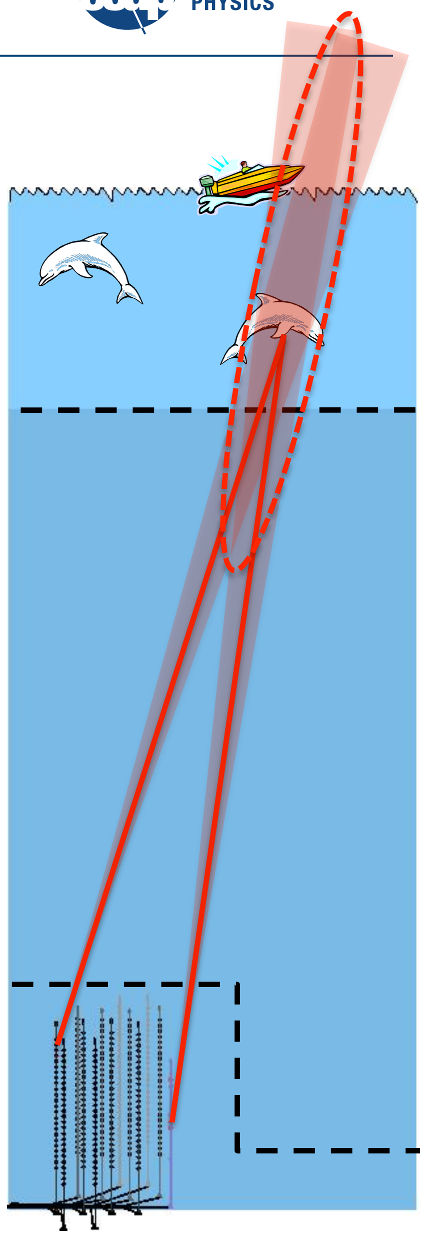
Small size of AMADEUS device
⇨ large errors in *z*, despite good angular resolution for direction reconstruction:

$\Delta\theta = 0.6 \pm 0.2^{\circ}$ in zenith

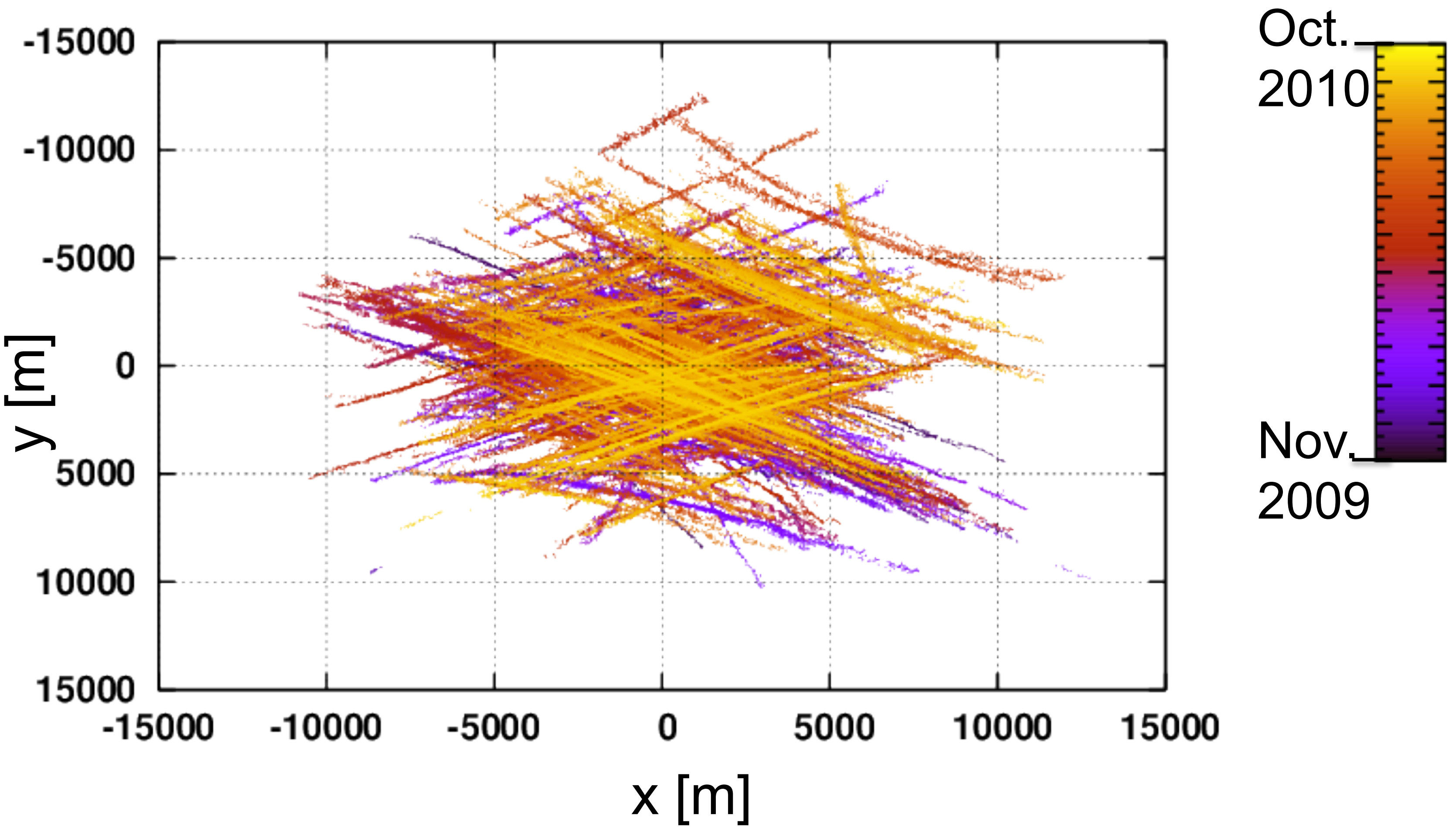
$\Delta\varphi = 1.6 \pm 0.2^{\circ}$ in azimuth

Solution:

Project positions to sea surface and remove event clusters from moving sound emitters



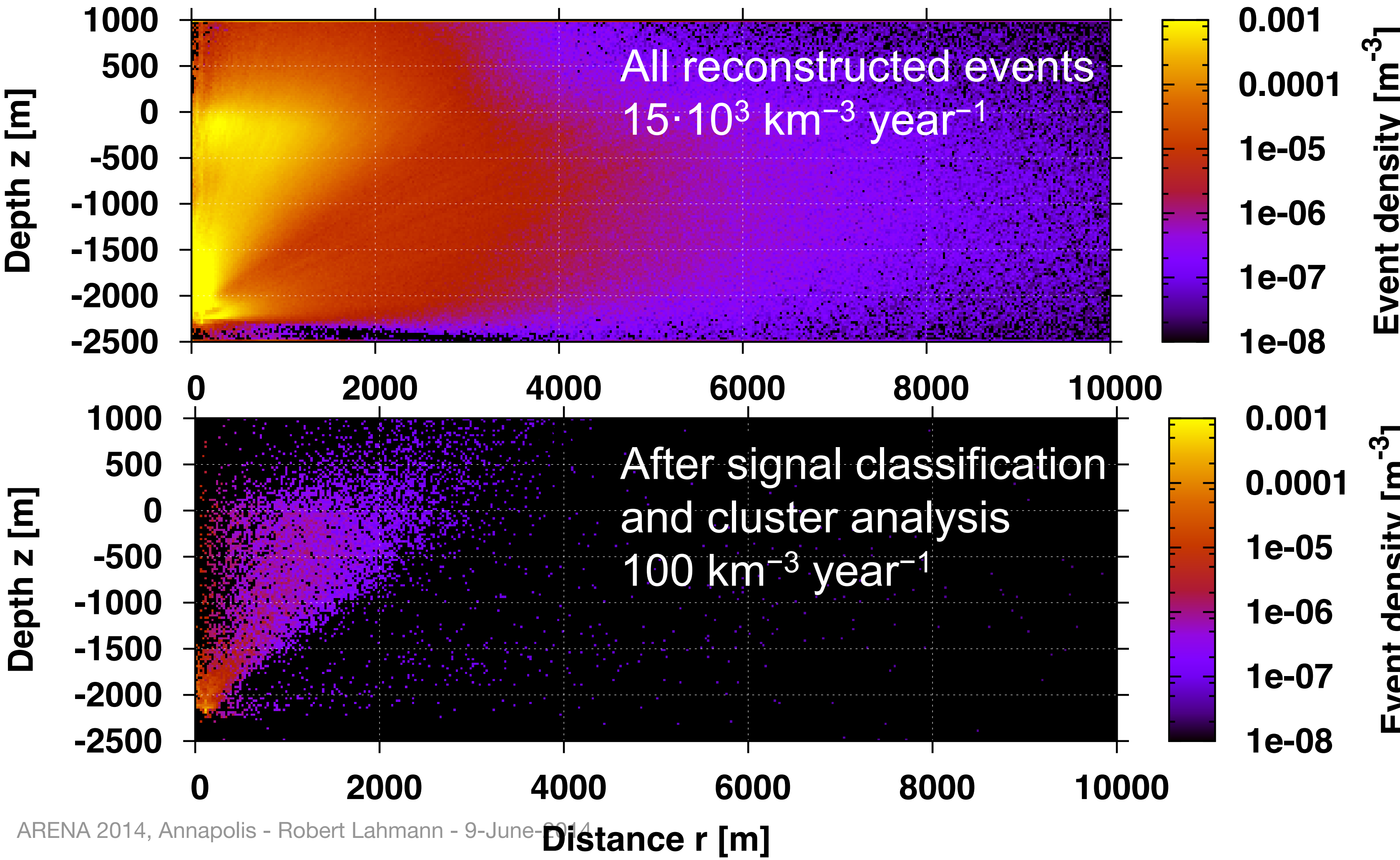
Cluster Analysis of Moving Sound Emitting Objects



Signal Classification with Machine Learning Algorithms

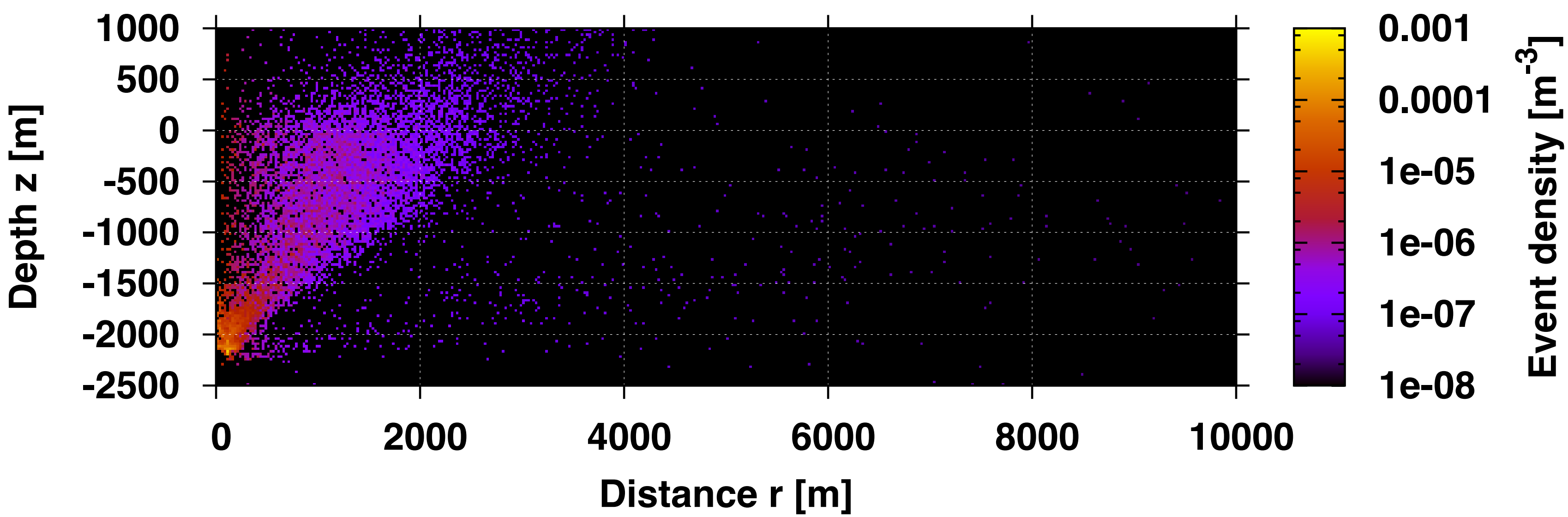
- Classification:
  neutrino candidate (BIP) ⇔ background
- Different algorithms have been investigated:
  - Random Forest } best performance
  - Boosted Trees }
  - Naïve Bayes
  - Decision Tree
  - Support Vector Machine
- Recognition Error:
  - For individual sensors < 10%
  - For clusters of sensors < 2%

Spatial Distribution of Transient Background



Search for a Fiducial Volume - Motivation

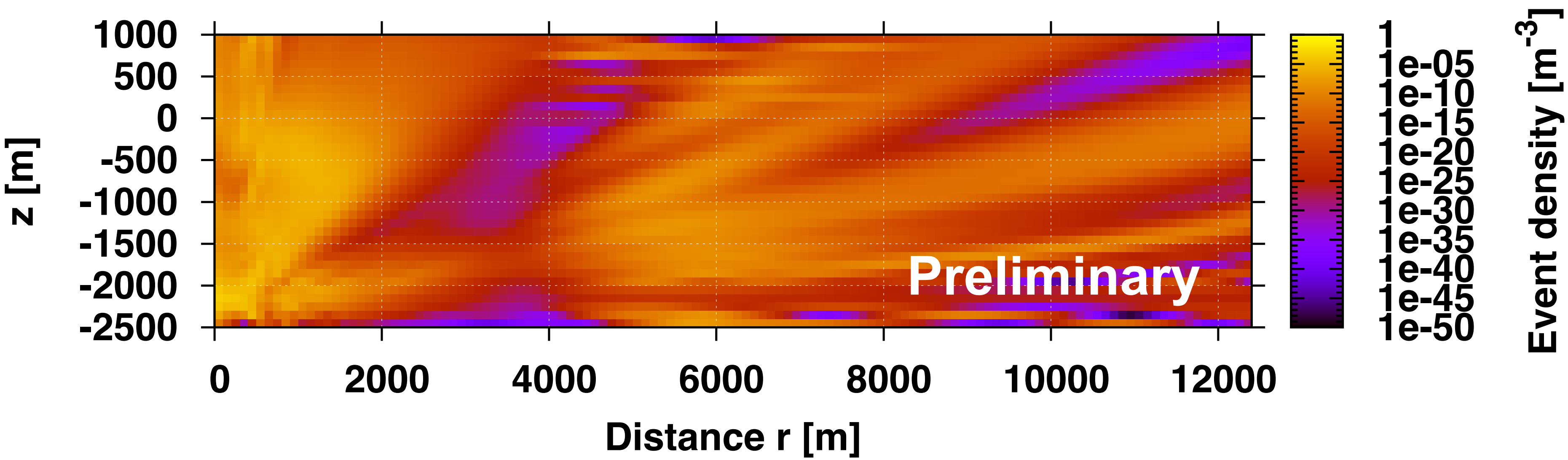
- Using signal classification and cluster analysis for the identification of neutrino-like bipolar signals
- Remaining events density: ~100 events/km^3/yr
- Need for further reduction ⇨ cut on the volume



Search for a Fiducial Volume - PSF

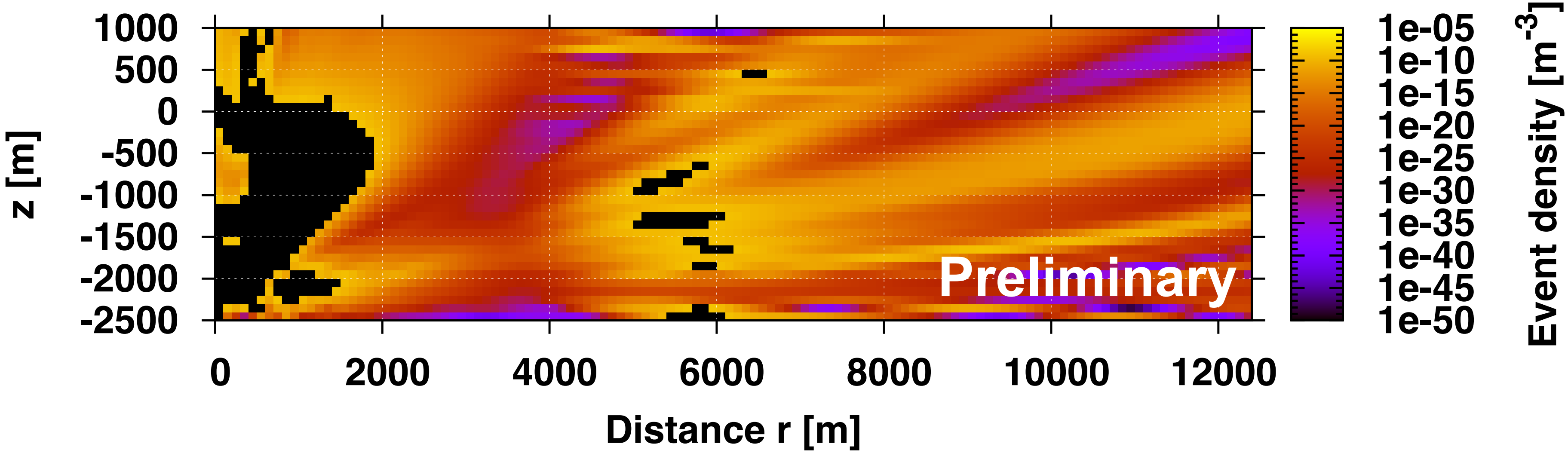
Optimize fiducial volume for minimal background content:

- 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

Probability of the neutrino reaching the vertex

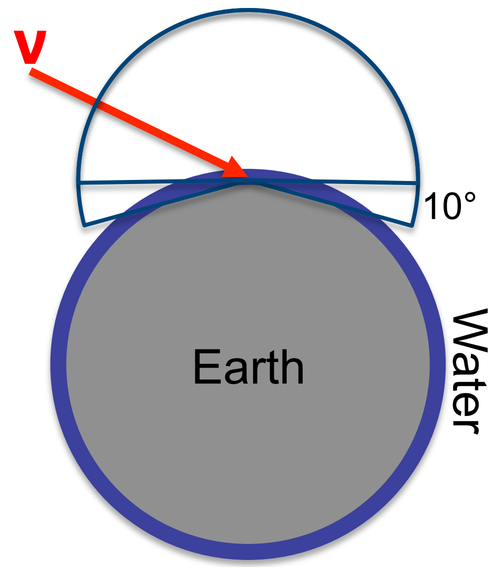
only counted if signal is detected;

$$V_{\mathrm{eff}} = \frac{\sum p(\mathrm{E}, \mathbf{x}, \mathbf{e}_p)\delta_{\mathrm{sel}}}{N_{\mathrm{gen}}} V_{\mathrm{gen}}$$

Effective Volume

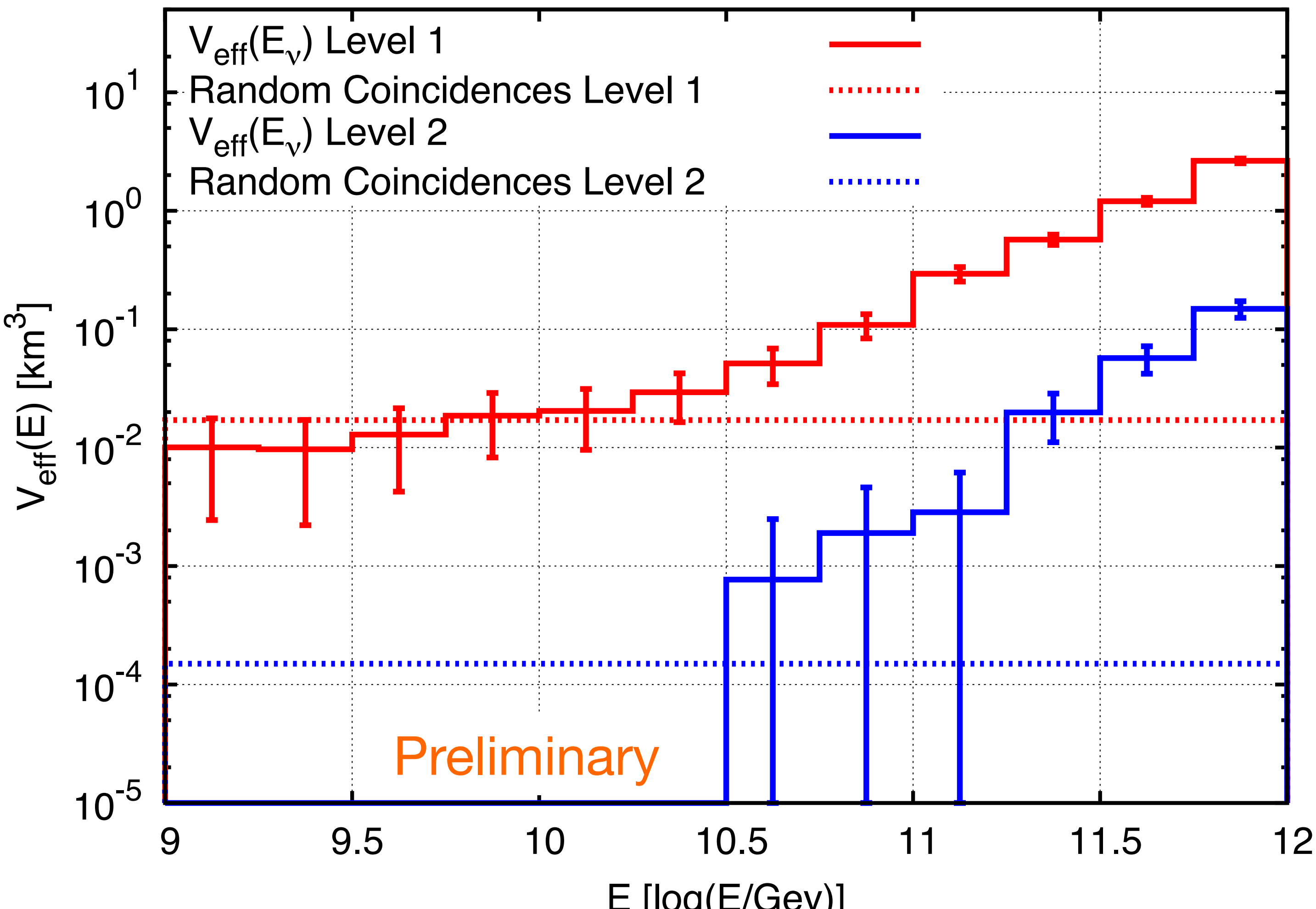
Number of Neutrinos: 10^7

Volume in which the Neutrinos are generated: $1200\mathrm{km}^3$



Earth density model (PREM)

AMADEUS Effective Volume



Level 1:

- low ambient noise
- minimal filter

Level 2:

- noise model (annual distr.)
- std. filter

AMADEUS: Lessons Learned

- Ambient background:
  GZK neutrinos (for pure proton flux) detectable, reduction of threshold crucial ⇨ 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