Acoustic neutrino detection investigations within ANTARES and prospects for KM3NeT

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VLVnT 2015
Rome, 14-Sept-2015

KM3NeT
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Outline

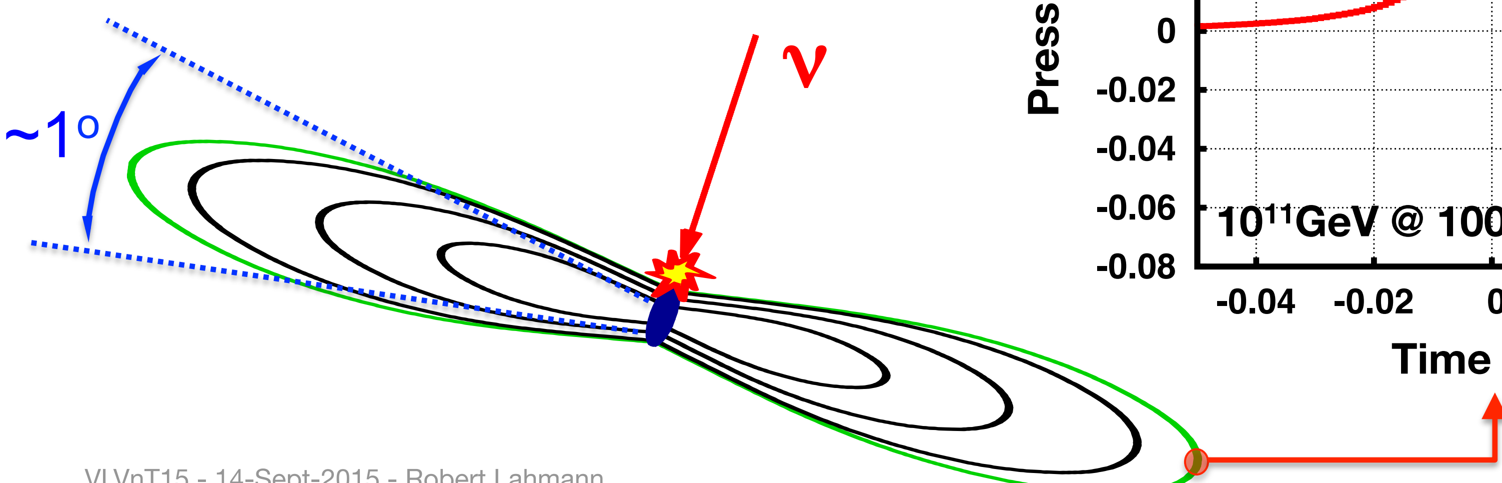
- Introduction: acoustic neutrino detection
- Lessons learned from AMADEUS
- Acoustics with KM3NeT
- Summary and conclusions

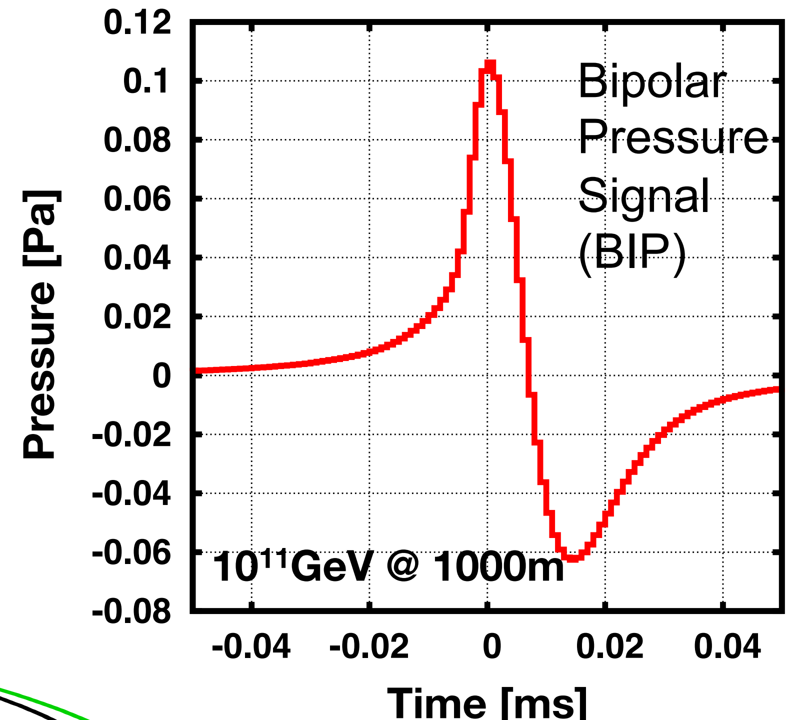
Acoustic detection of neutrinos

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

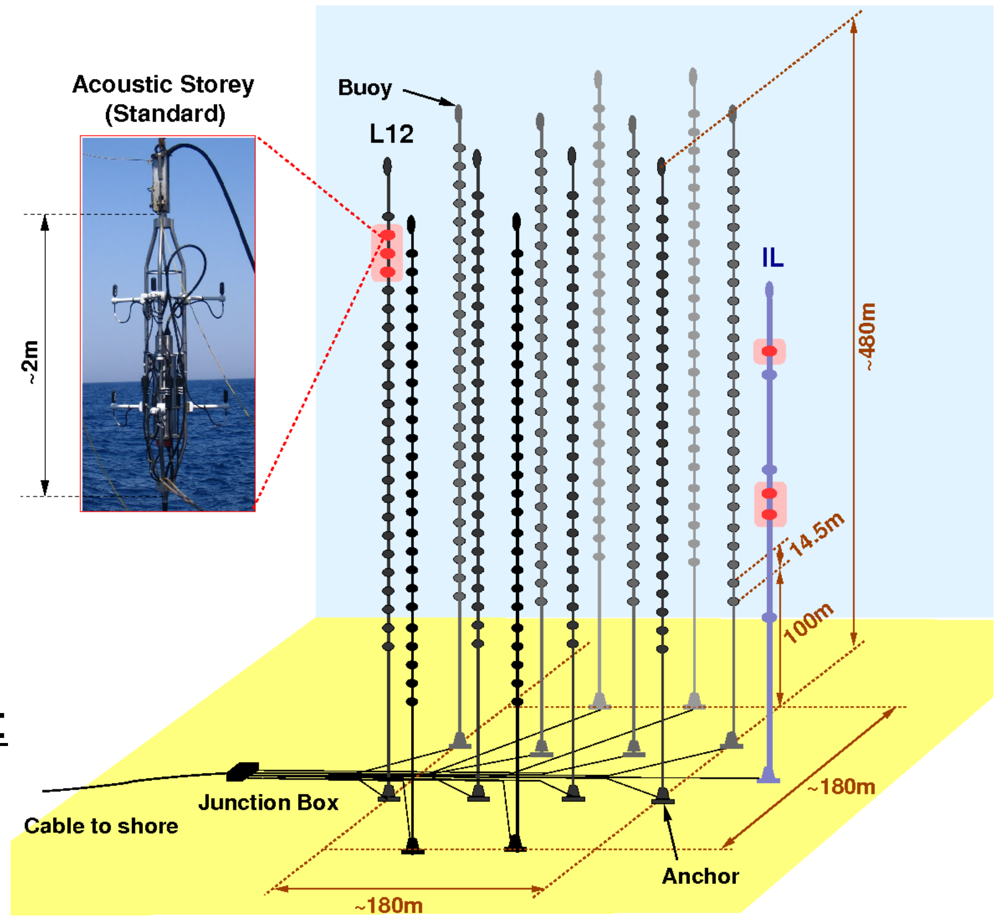
Hadronic cascade:
~10m length, few cm radius

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





The AMADEUS system of the ANTARES detector

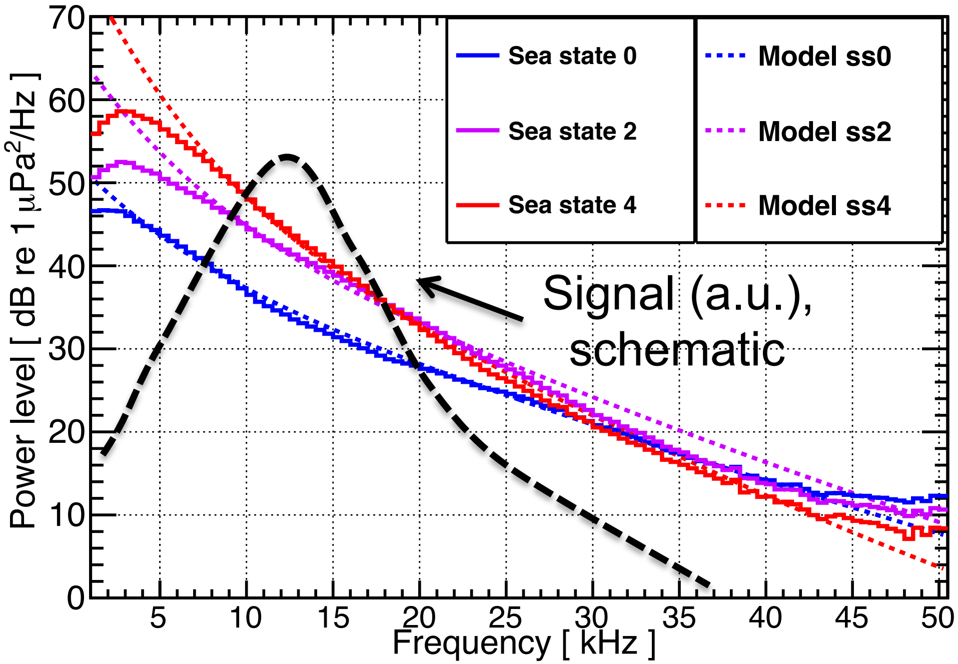


ANTARES site:
- 2500m depth, 30km offshore

AMADEUS
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

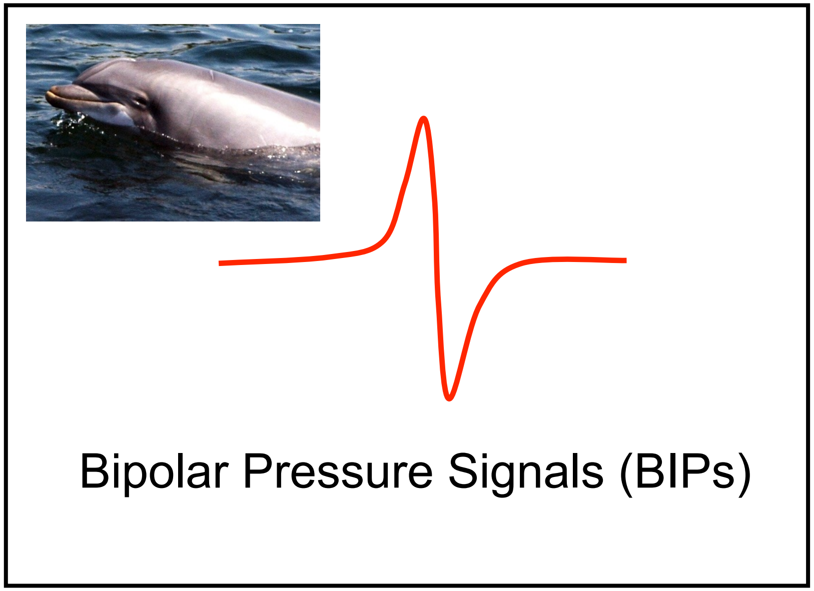
Ambient noise



⇨ **Determines intrinsic energy threshold**

Depends on "sea state" (surface agitation)

Transient background



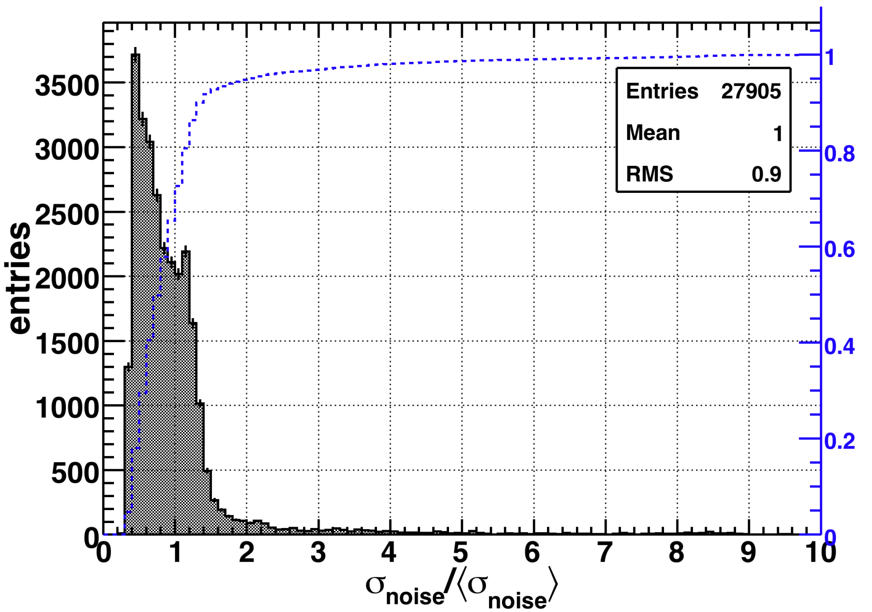
⇨ **Determines fake neutrino rate**

Suppress by
- clustering
- signal classification
- fiducial volume cuts

Ambient noise – occurrence distribution

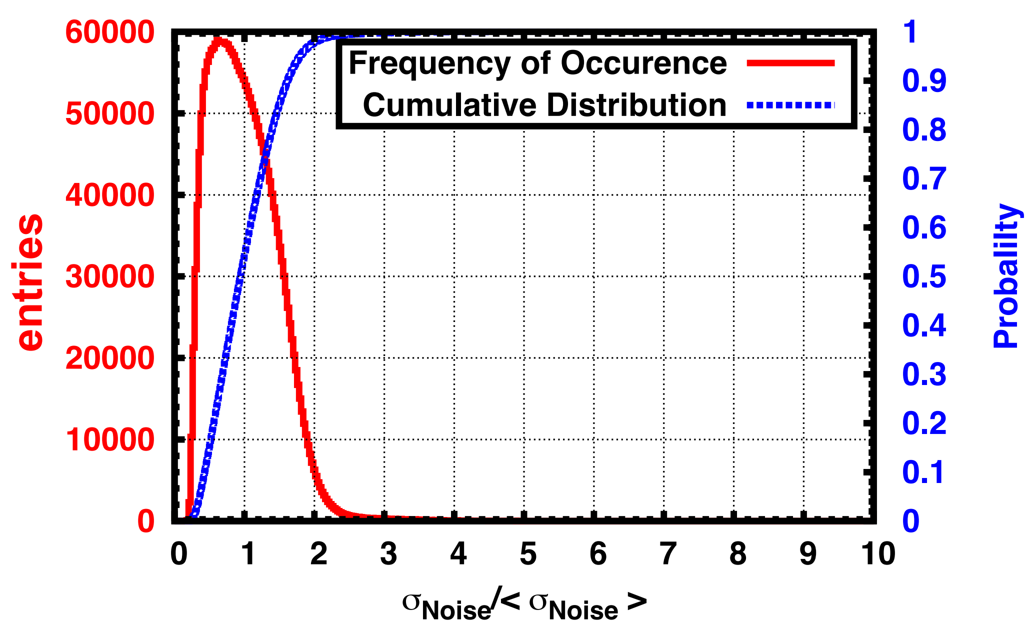
Main source: Surface agitation and precipitation

Measurement



Data of 2008-2010

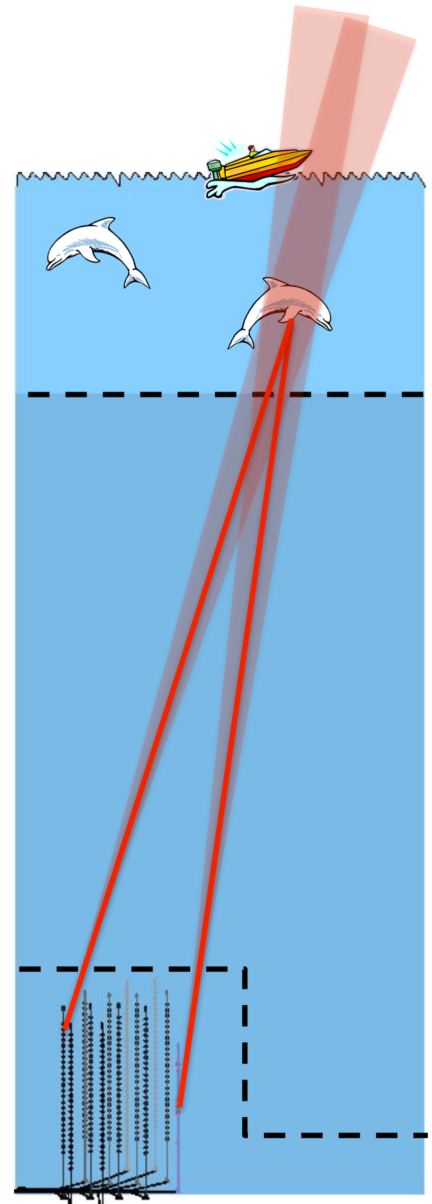
Simulation



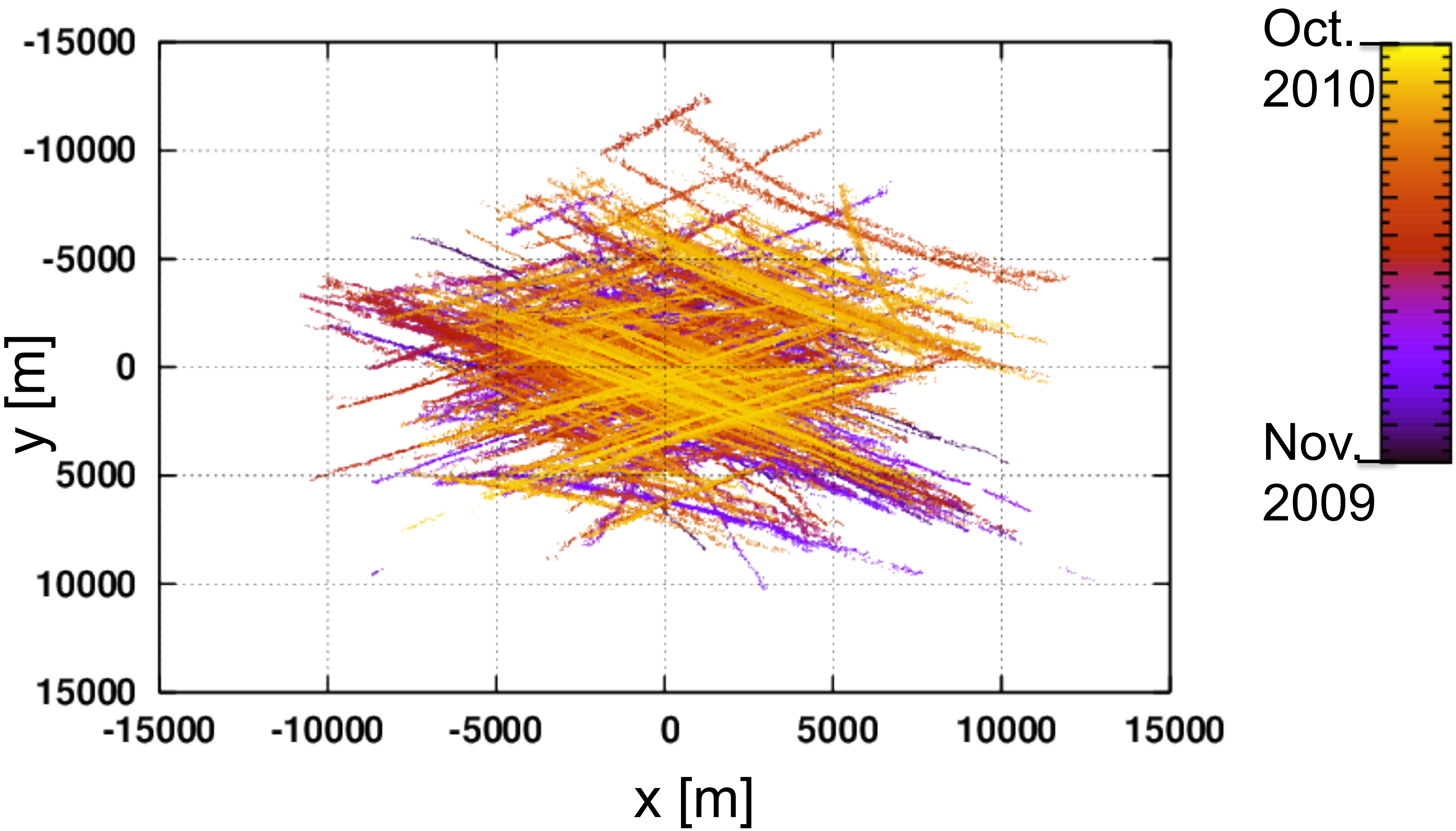
$<\sigma_{noise}>$ is about 10 mPa (10-50 kHz) and 95% of the time below $2<\sigma_{noise}>$

Transient background

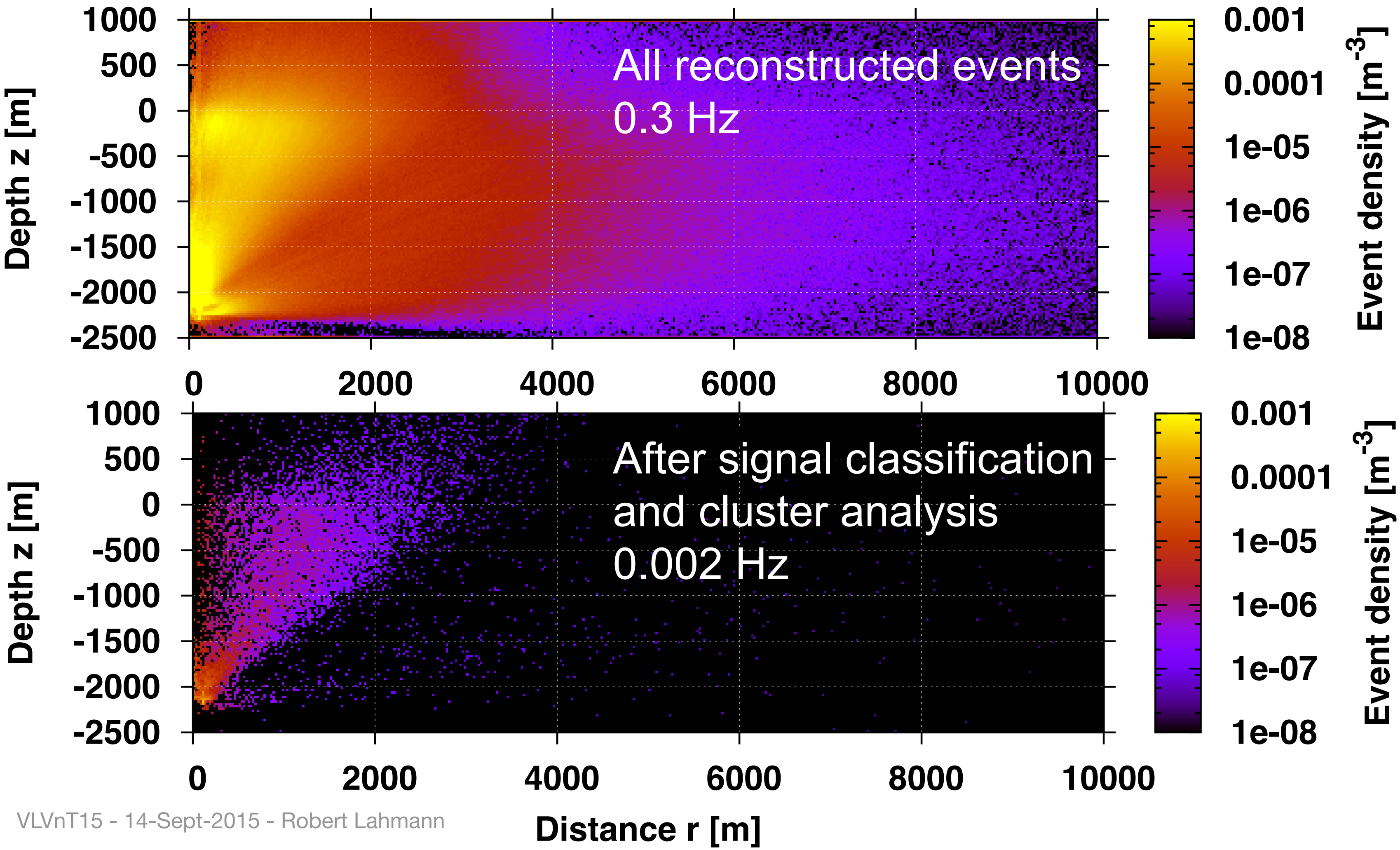
- Sources: Very diverse;
  Shipping traffic, marine mammals, …
  ⇨ Mostly originating from near surface
- Suppression:
  - signal classification
  - Project reconstructed signals to surface, perform clustering



Cluster analysis of moving sound emitting objects



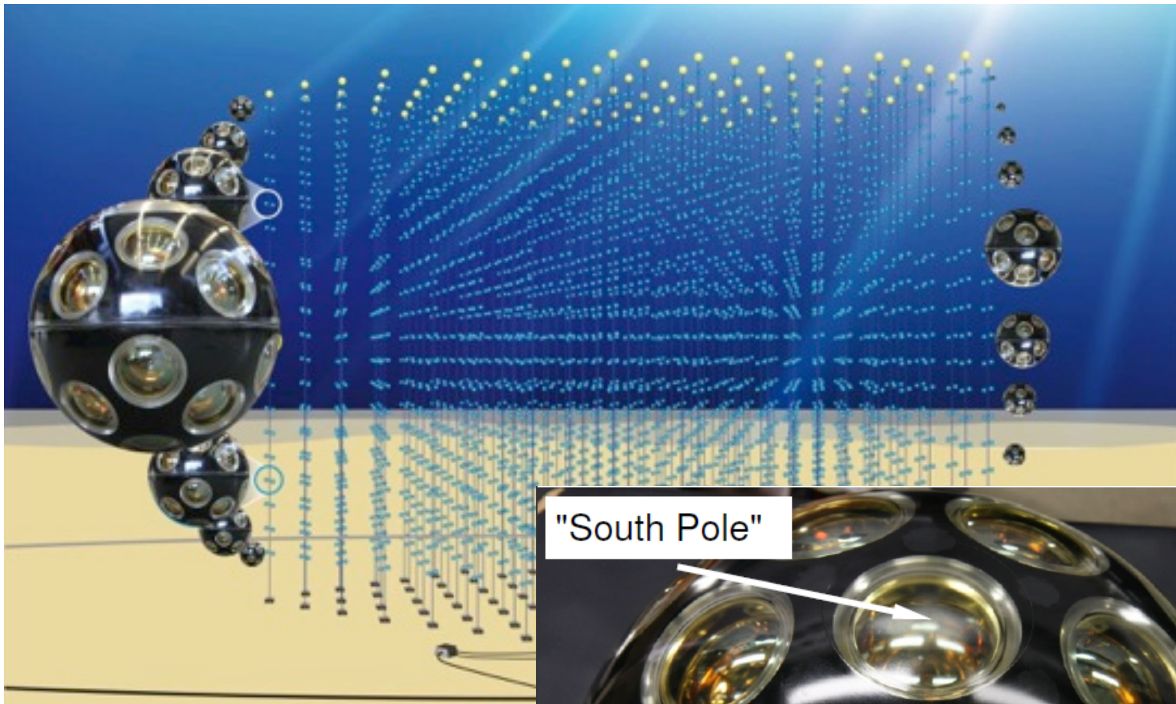
Spatial distribution of transient background



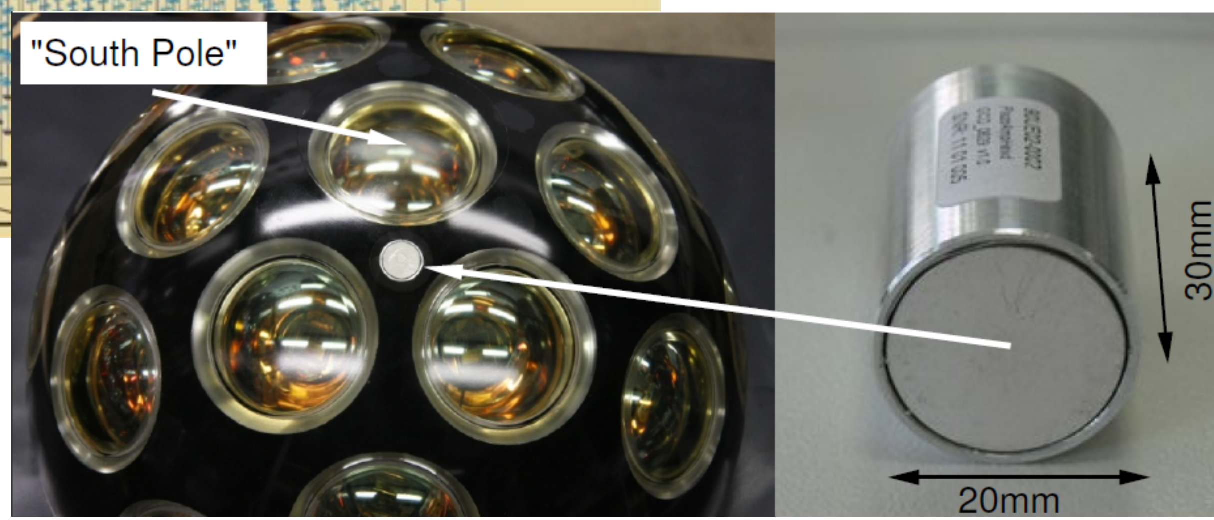
AMADEUS: lessons learned

- 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



Acoustics in KM3NeT

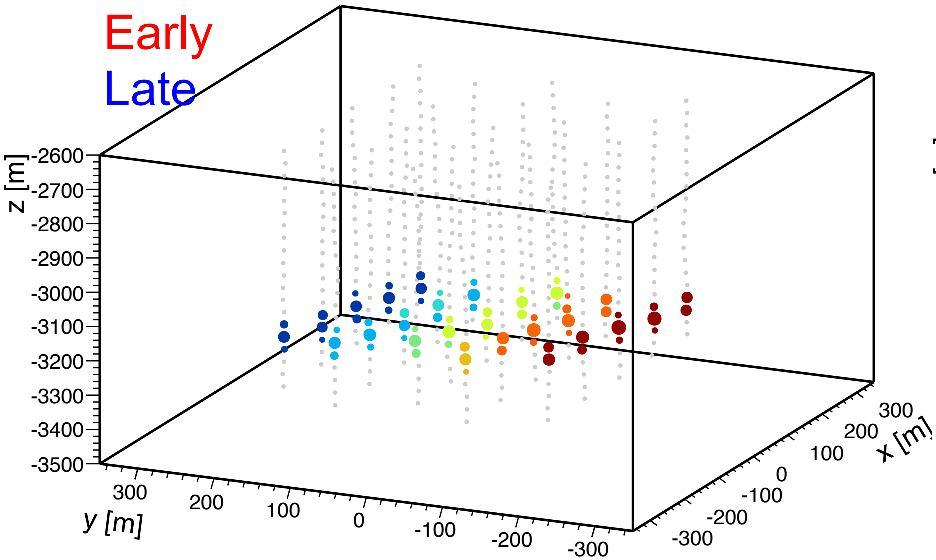
- Acoustics with positioning system “for free”
- Acoustic neutrino detection part of long-term KM3NeT strategy
- In the long run: optical hydrophones (see talk by E.-J. Buis)
- Great interest in acoustic sensing from marine scientists

The crucial questions for acoustic neutrino detection:

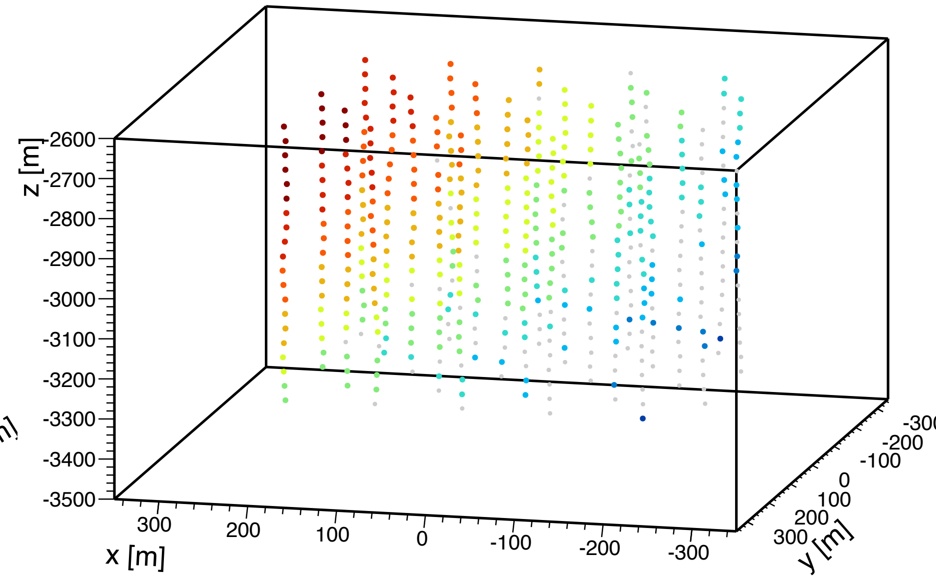
- Can we classify neutrinos background-free?
- Energy threshold?
- What volume do we need?

Simulated events

Neutrino @ 1.8 km, E=10^{21}eV, Θ=16°



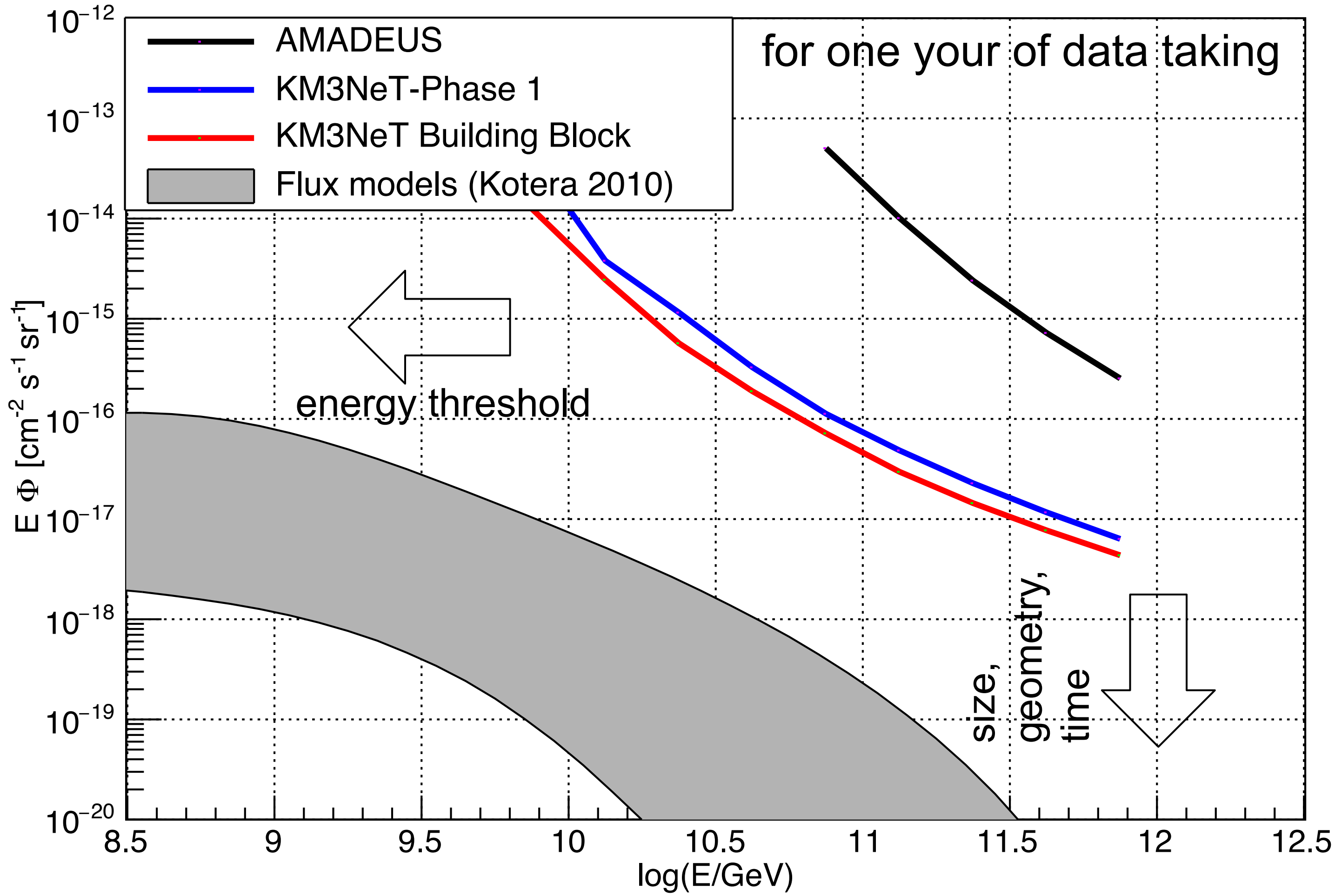
Spherical background (e.g. ship)



- 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 4×10^{-7} Hz per ARCA-block
(Further reduction needed!)

Simulation: „Transient free limit setting potential“



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

Bundesministerium für Bildung und Forschung

Thank you for your attention!

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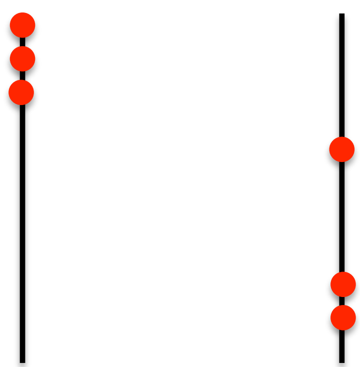
Backups

KM3NeT Phase 1 compared to AMADEUS

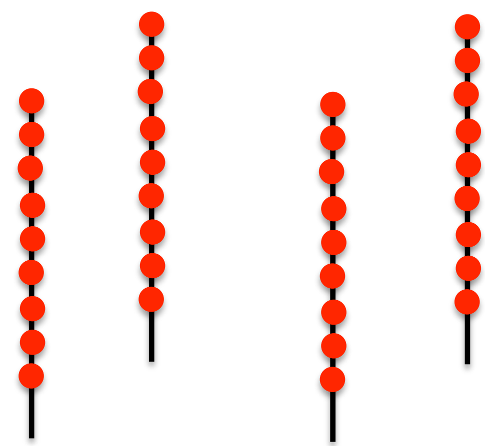
AMADEUS

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



KM3NeT Phase 1

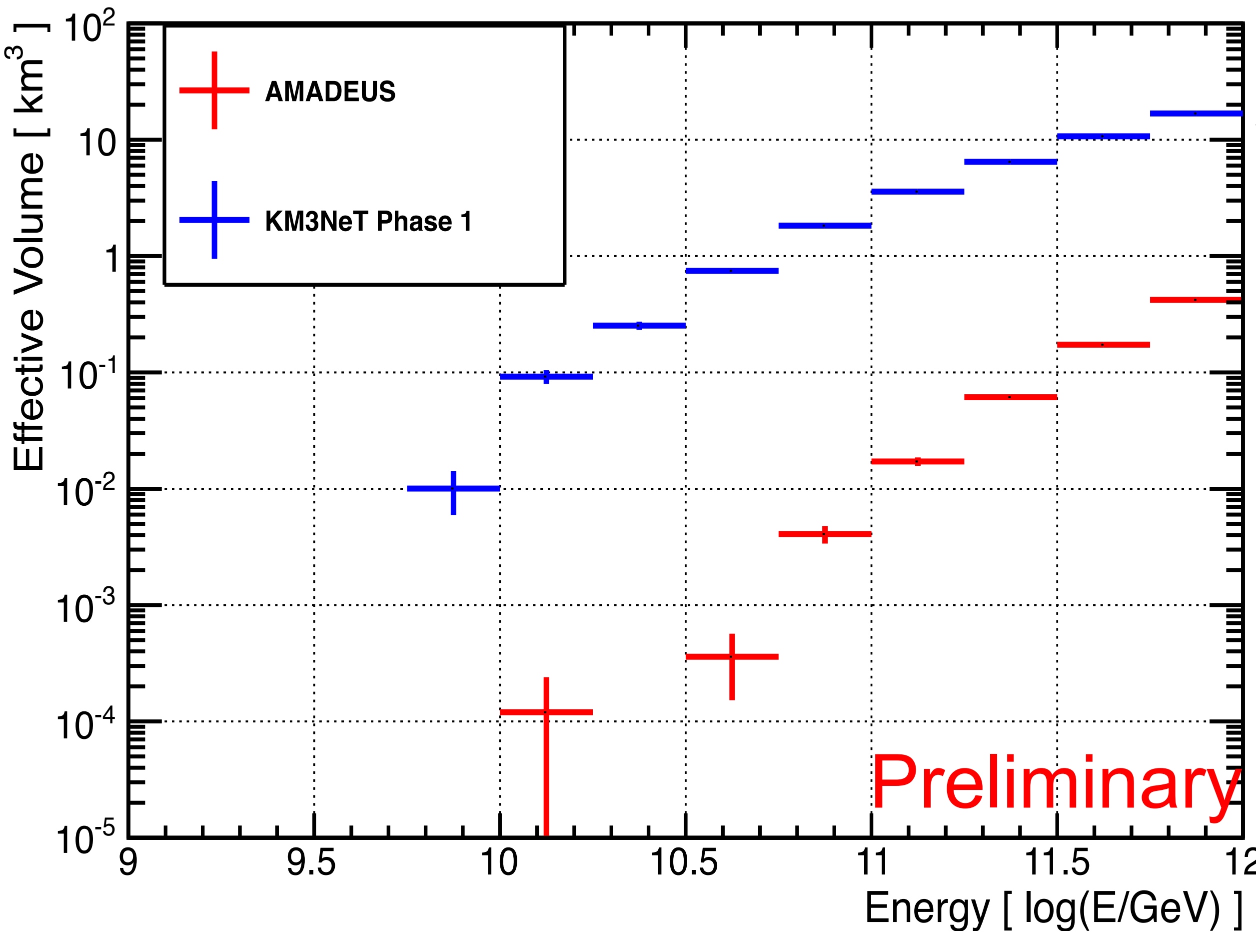
- 24 lines, 100m apart
- 18 optical modules/line, 36m
    - 1 acoustic sensor/module



Comparing apples and oranges:

- 2D setup vs. 3D setup
- Different number of sensors per cluster

Effective volume for acoustic detection



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

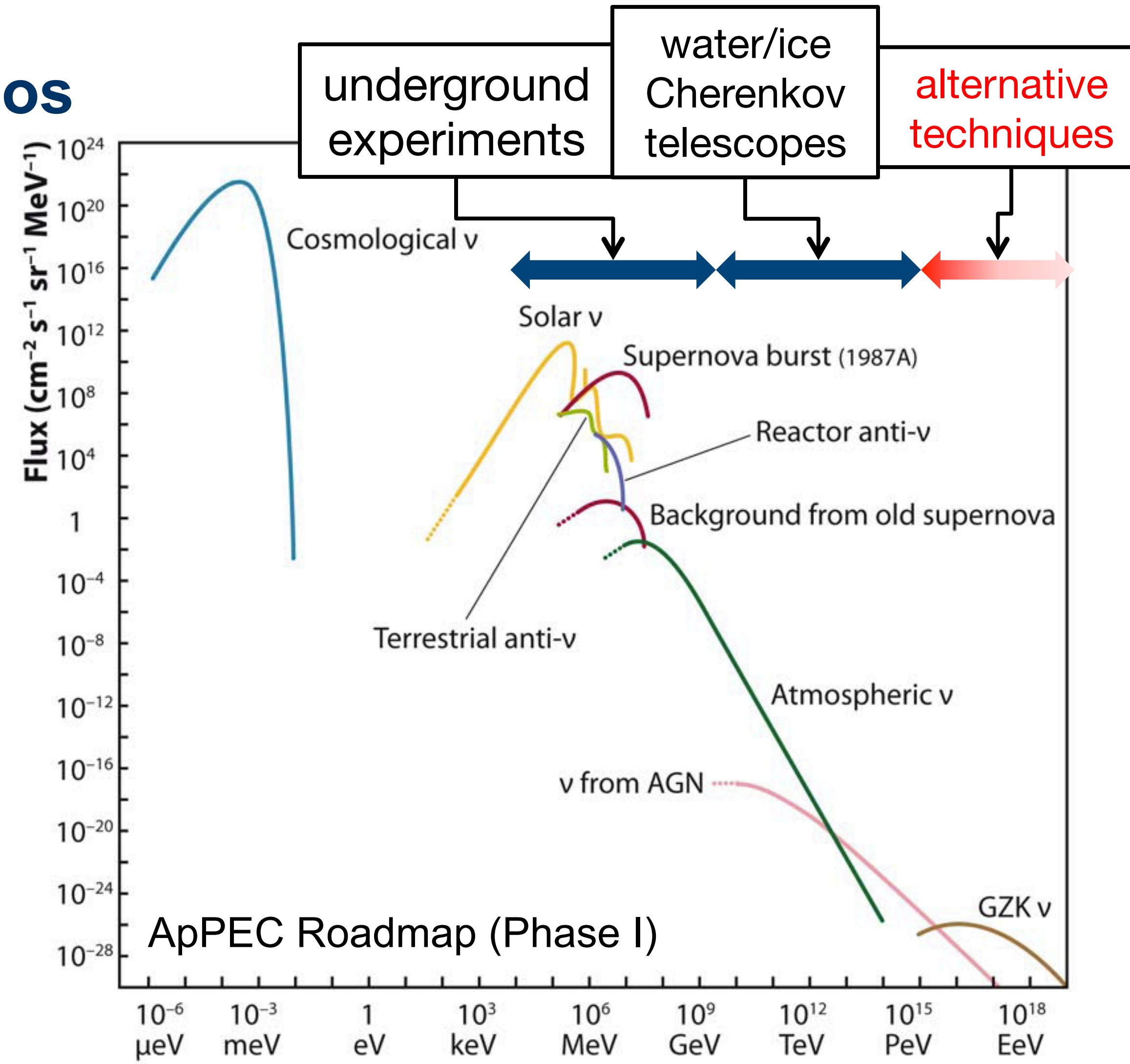
Noise: 15 mPa
Min. SNR: >2
Min. #Sensors: 6

Cosmogenic neutrinos

"GZK neutrinos"

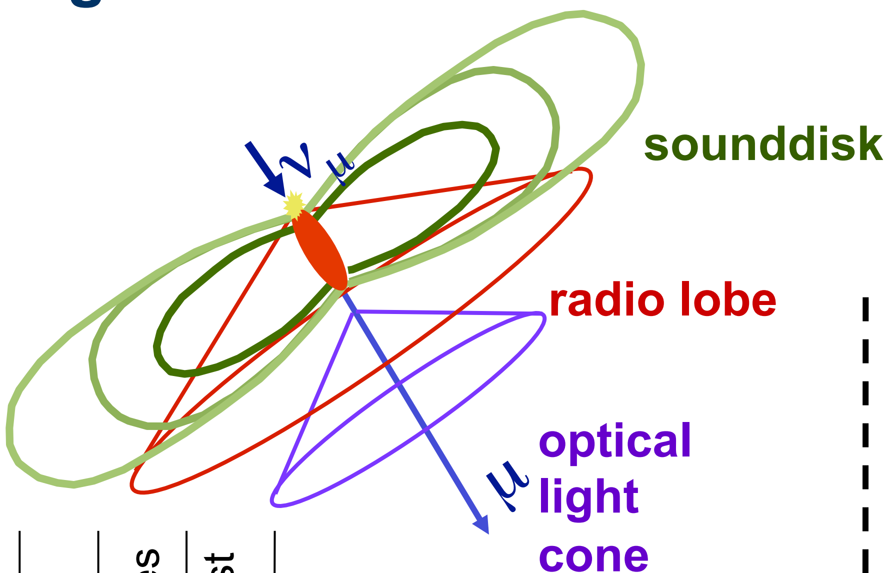
produced in interactions of CRs at highest energies with CMB photons

$$p + p(\gamma) \rightarrow \pi + X$$
$$\hookrightarrow \mu + \nu_\mu$$
$$\hookrightarrow e + \nu_e + \nu_\mu$$

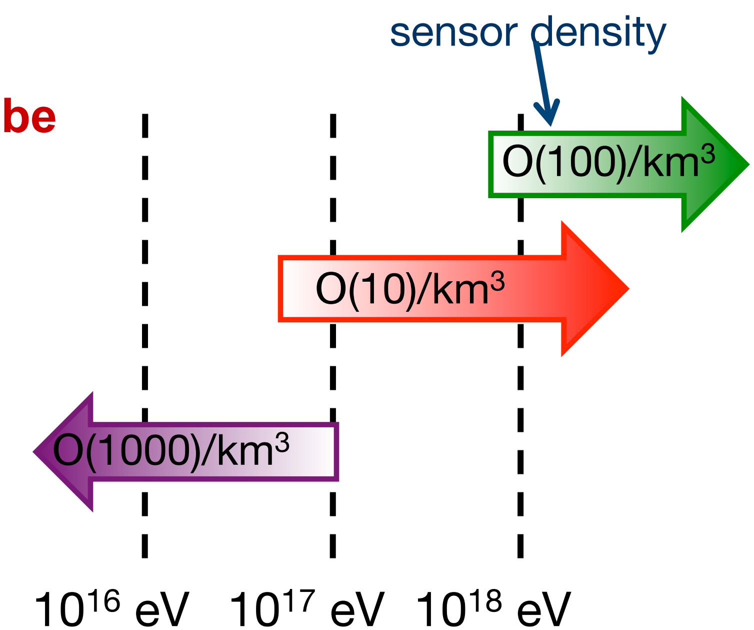


for GZK ν: >100km² · 2π · year detector needed

Neutrino signatures in different media



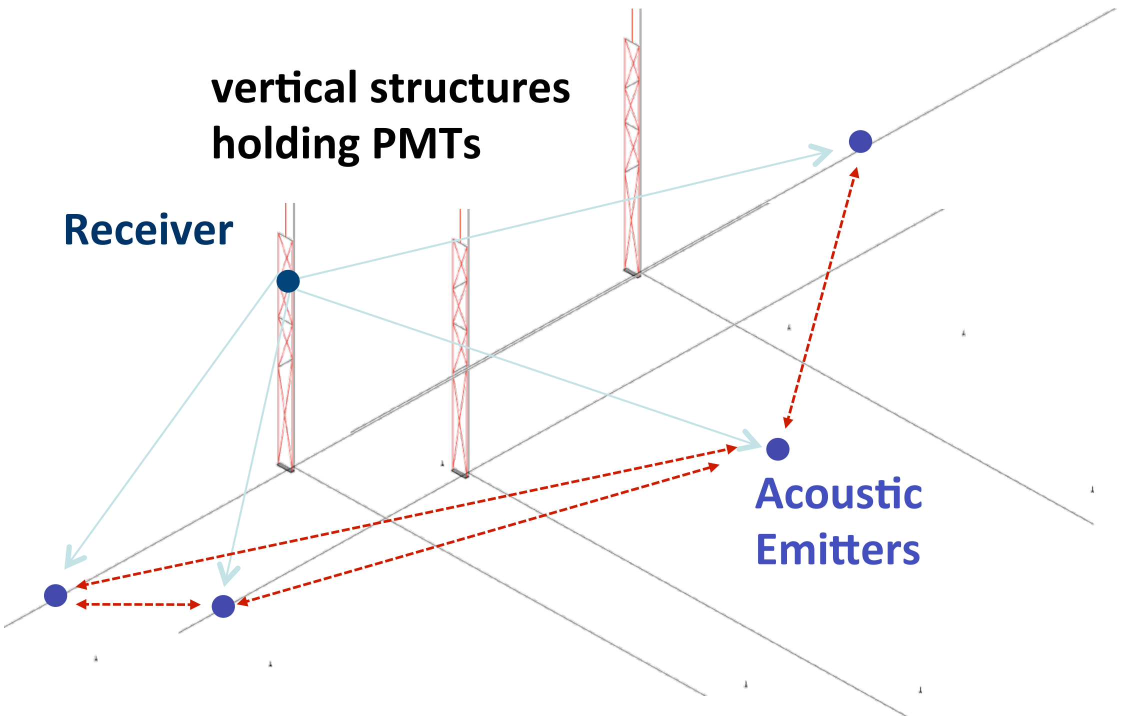
	Ice	Water	Salt domes	Permafrost
light	✓	✓		
radio	✓		✓	✓
sound	✓	✓	✓	✓



adapted from: R. Nahnhauer, ARENA Conf. 2010

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:

$\Delta\theta = 0.6 \pm 0.2^\circ$ 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

Sound in water

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

(R. Urick, Principles of Underwater Sound, 3rd edition, 1967)

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)