Status and Recent Results of the South Pole Acoustic Test Setup

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for the IceCube collaboration

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IceCube

BERGISCHE UNIVERSITÄT WUPPERTAL

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Großgeräte der physikalischen Grundlagenforschung

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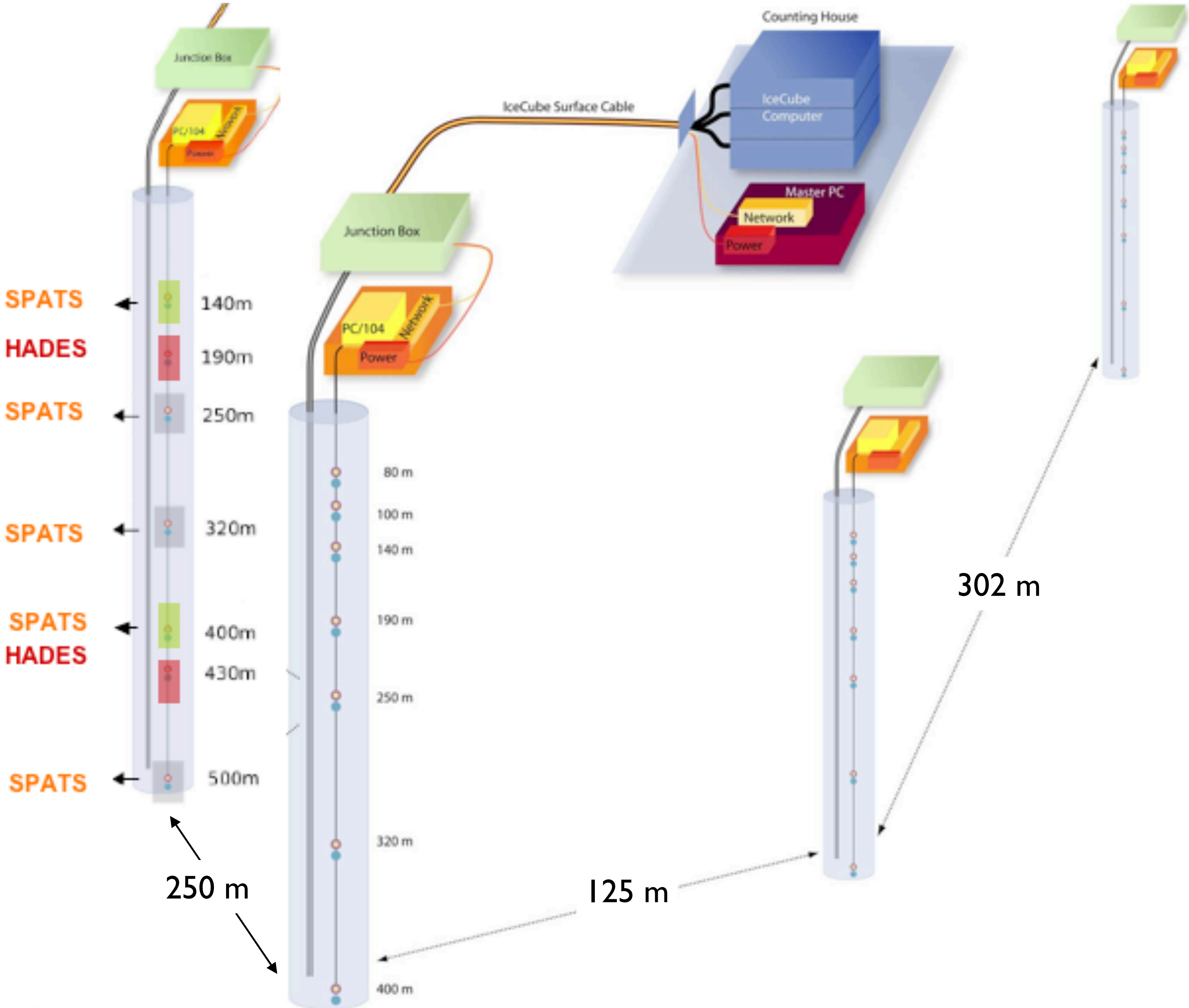
Aim of SPATS: Ice properties (10 − 100 kHz)

➡ Get realistic sensitivity estimate for an acoustic neutrino telescope in ice

- Speed of sound and its variation with depth
  - significant refraction would make vertex reconstruction difficult
- Attenuation length
  - determines sensor spacing / effective volume of neutrino detector
  - frequency dependence allows to determine attenuation mechanism
- Noise floor
  - determines energy threshold
- Transient noise sources
  - impulsive noise must be separated from neutrino signal

Hardware overview

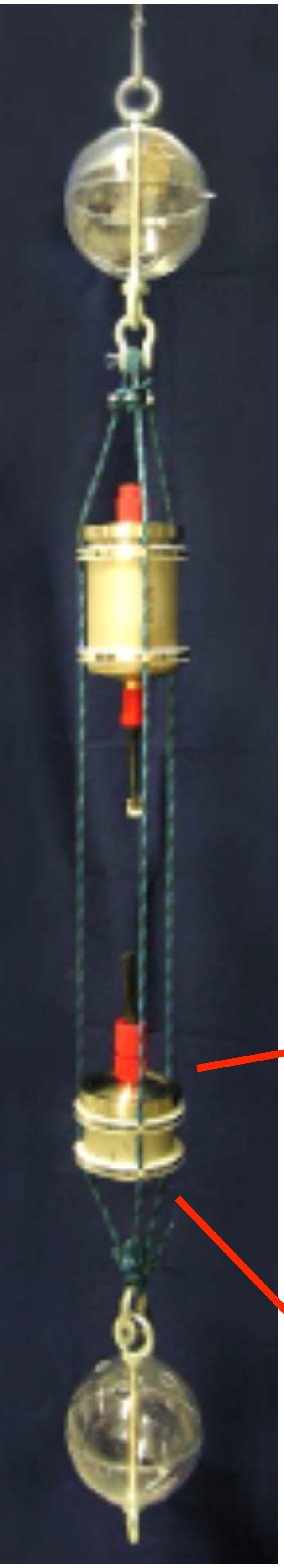
South Pole Acoustic Test Setup (SPATS)



- 4 strings in IceCube drill holes
- instrumented depth: 80 m − 500 m
- per string:
  - 7 sensors
  - 7 transmitters
- String-PC
  - digitization
  - time stamping
  - monitoring (p, T)
- Master-PC
  - data storage
  - GPS clock
  - data transfer via satellite

Strings A, B, C installed in 2006/07
String D installed in 2007/08

SPATS stage design

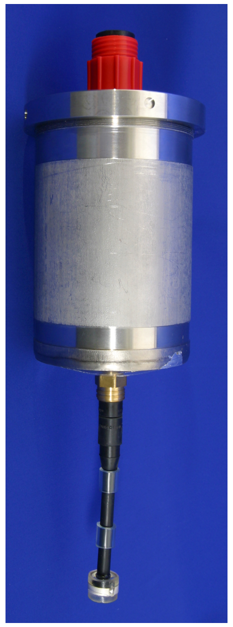


Transmitter:

- ring shaped piezo ceramic coated in resin
- HV generator

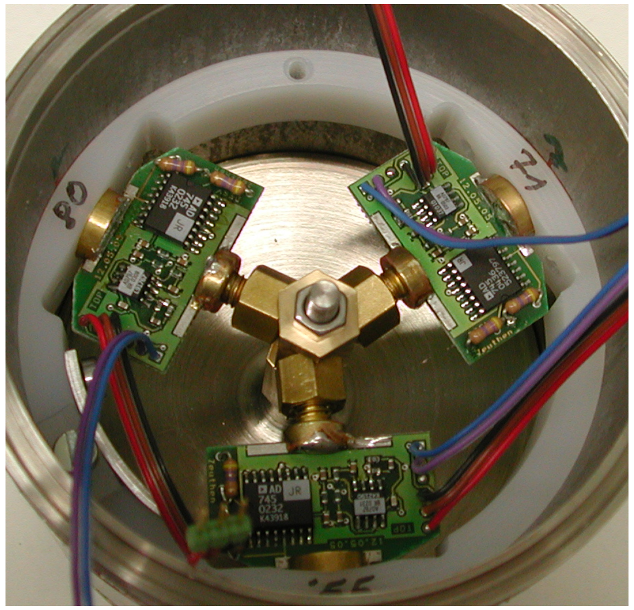
Sensor:

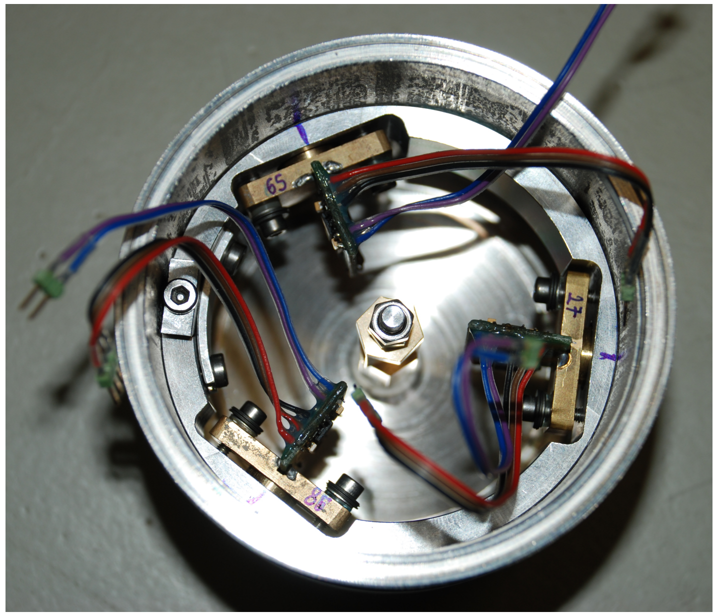
- 3 channels / sensor
- pre-amplifier
- analogue signal transmission
- steel pressure housing



String-D:

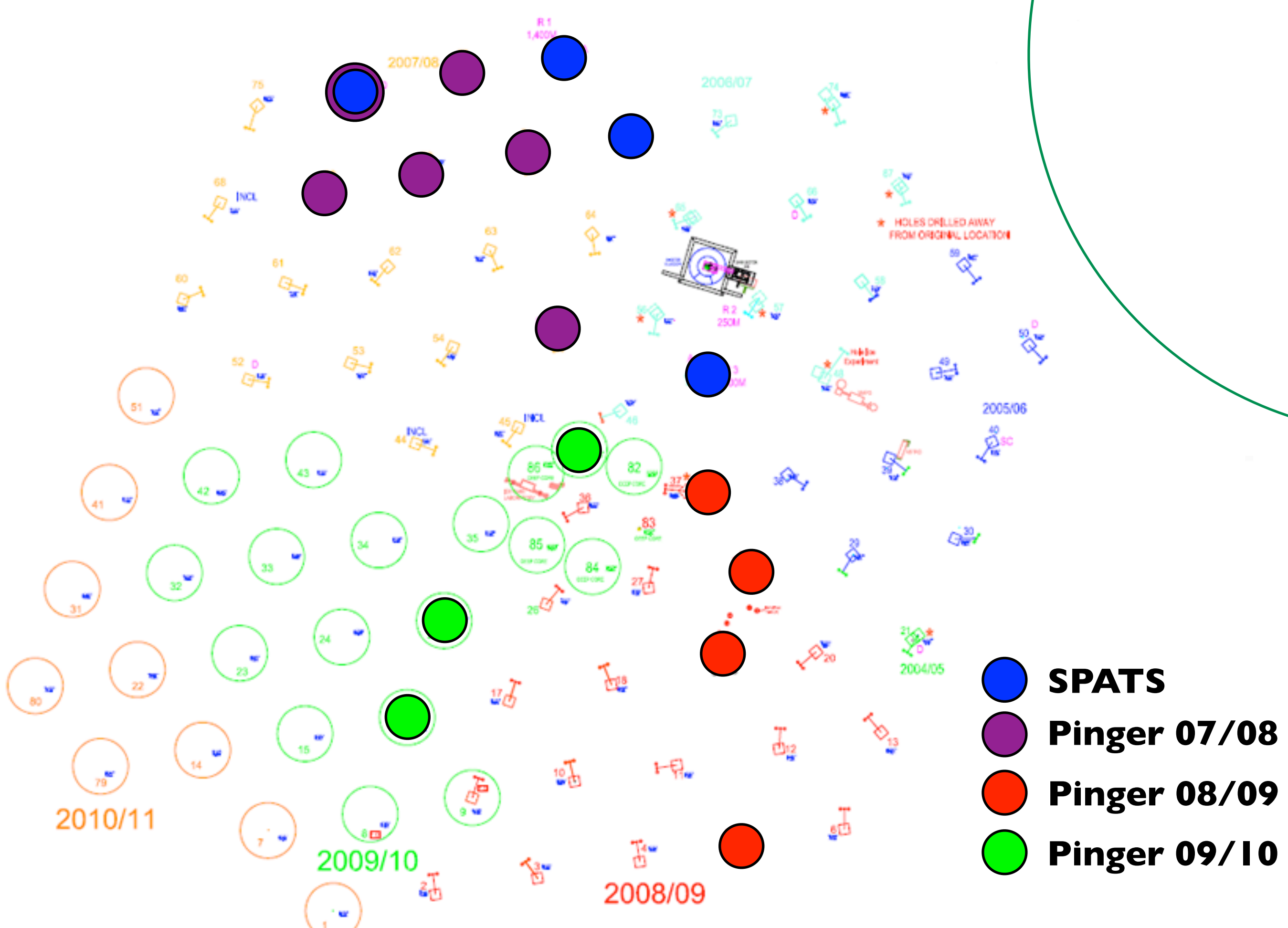
- improved sensors:
  mechanical decoupling of sensor channels
- improved transmitters:
  higher power
- HADES:
  alternative sensor design with piezo ceramics outside the steel housing

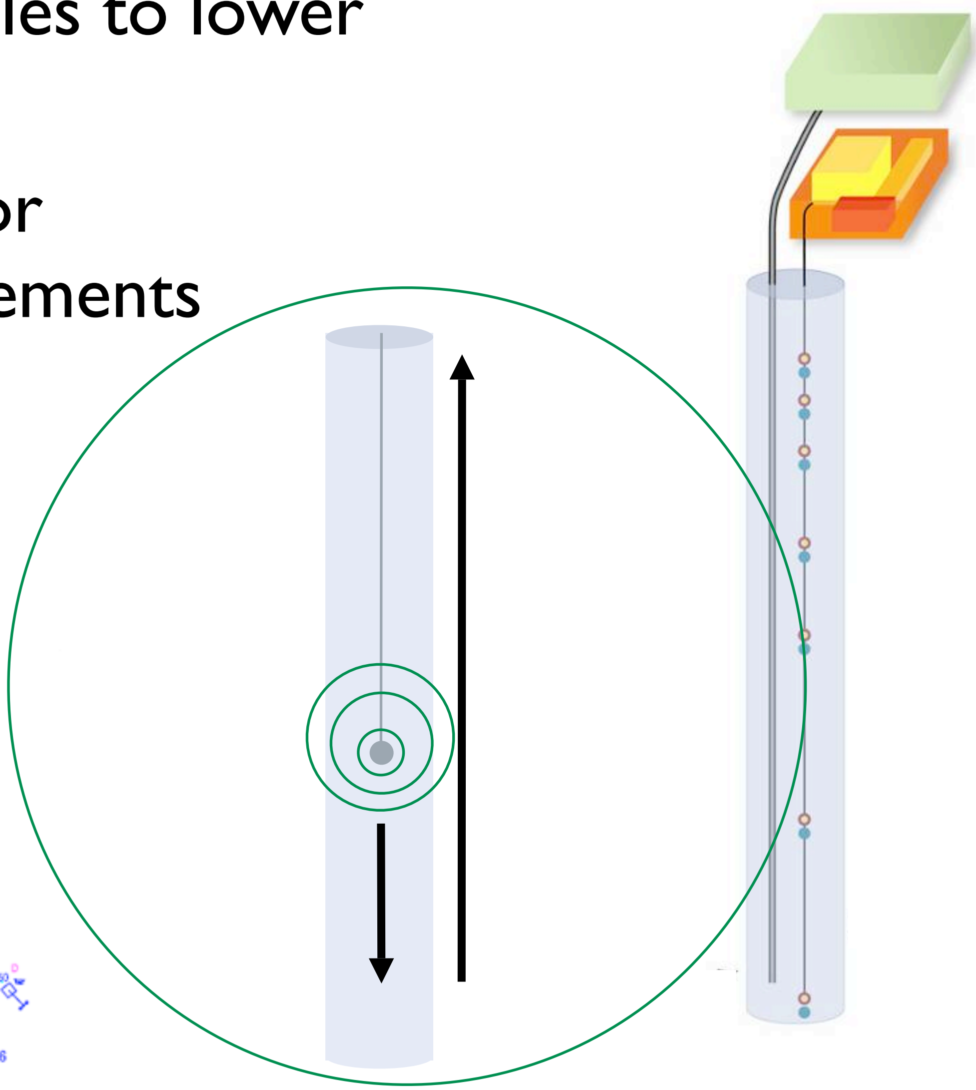




Extended range: The retrievable pinger

- Use newly drilled IceCube holes to lower retrievable transmitter
  - increased distance range for attenuation length measurements
  - sound speed depth profile
  - relative sensor calibration





Speed of sound

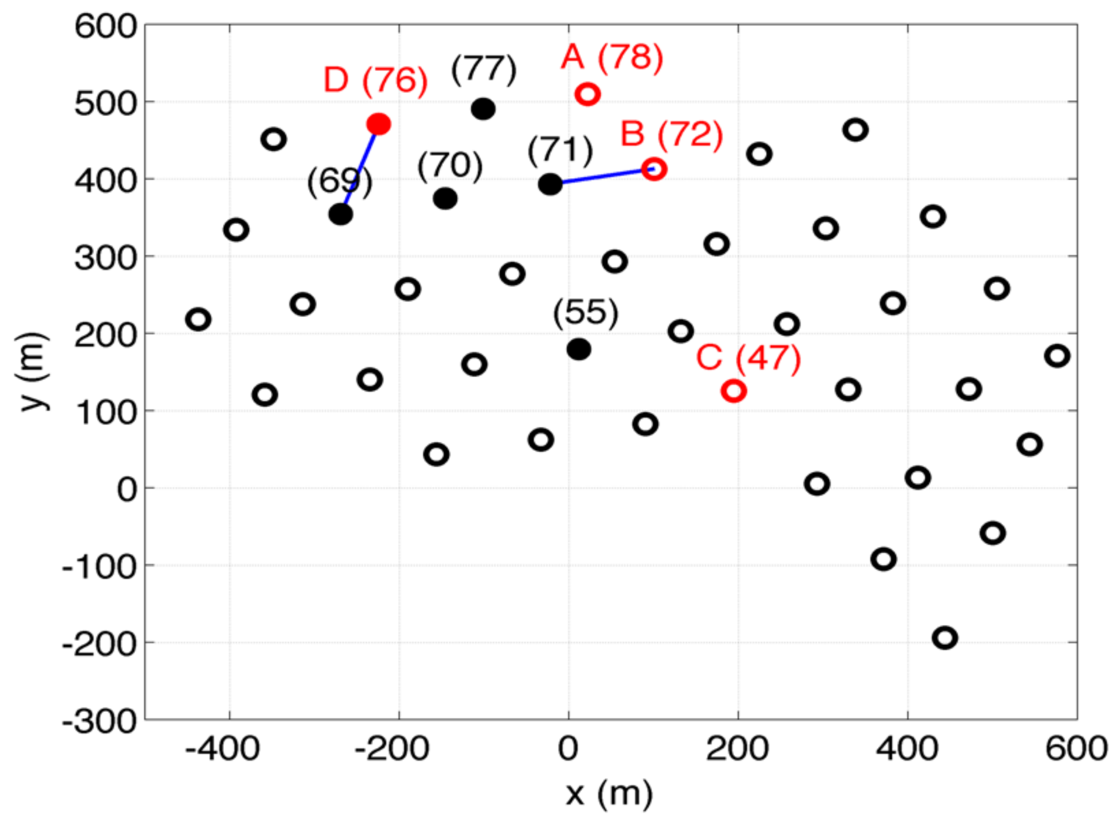
Astropart. Phys. **33** (2010) 277, arXiv:0909.2629 [astro-ph.IM]

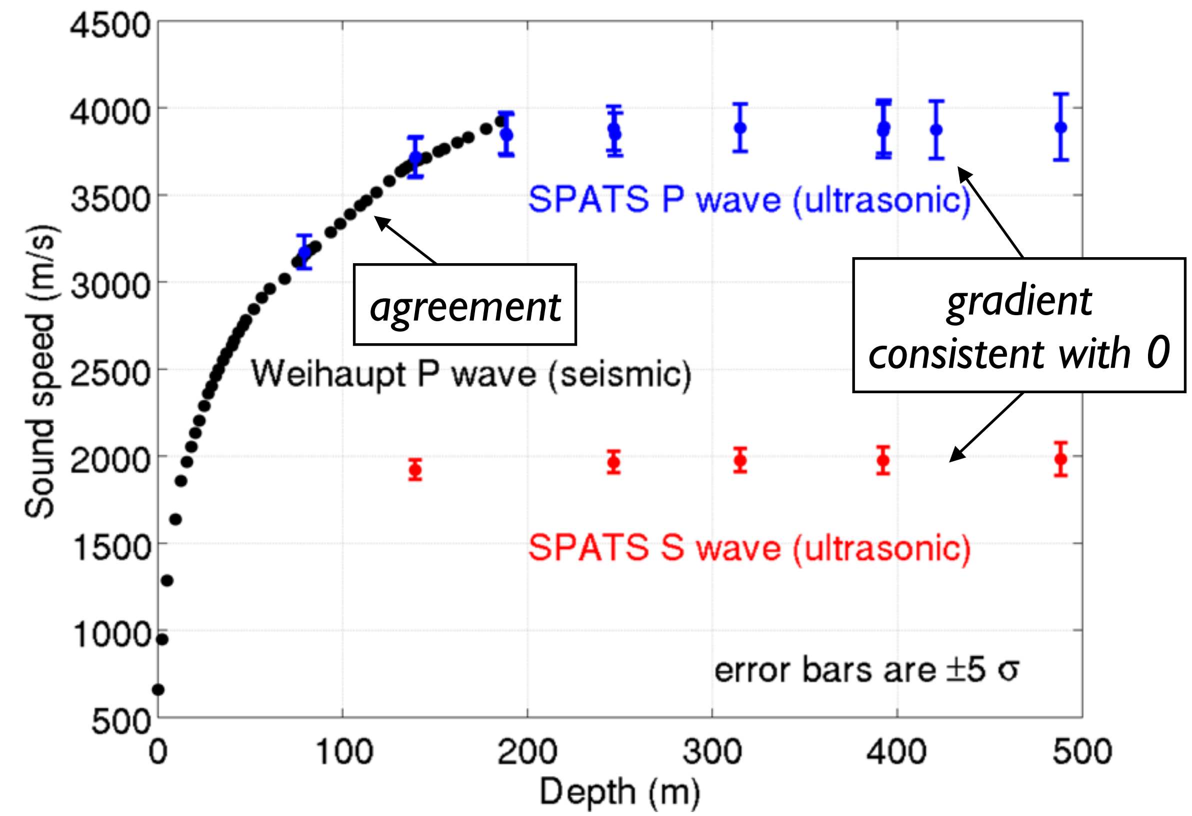
&

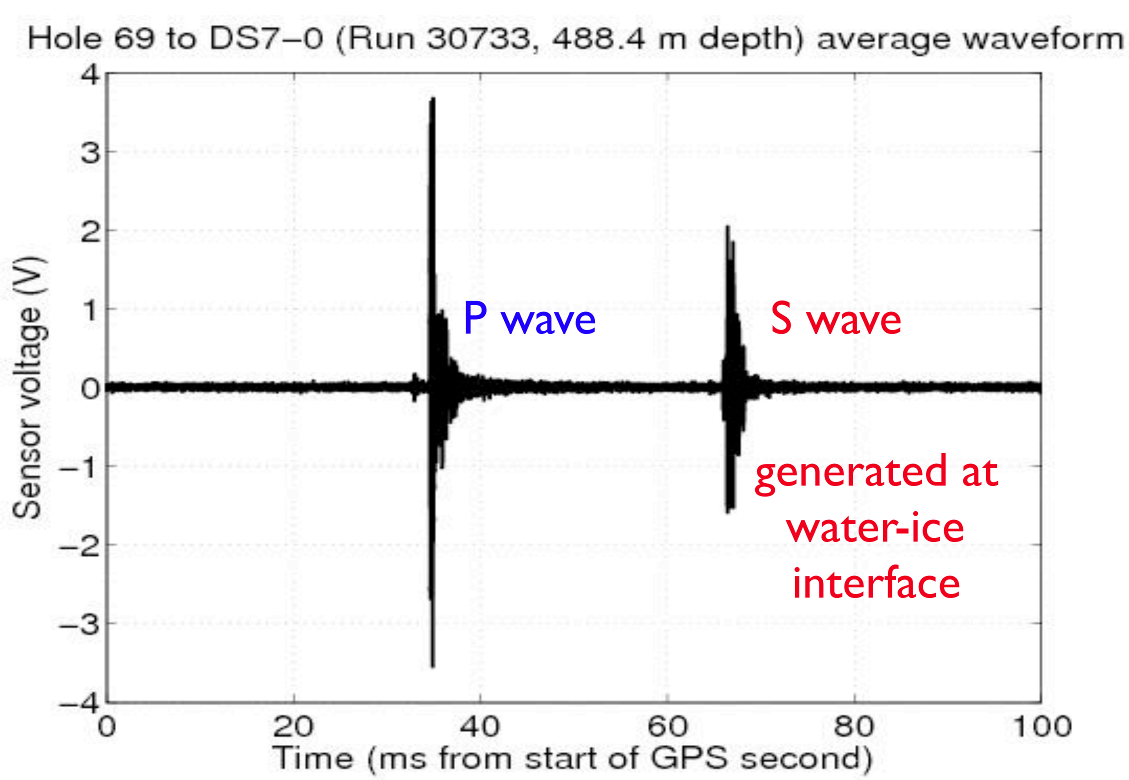
Attenuation length

submitted to Astropart. Phys., arXiv:1004.1694 [astro-ph.IM]

Sound speed depth profile







- 2 combinations, 125 m distance from pinger data season 2007-2008
- Better than 1% accuracy
- First measurement in situ for P and S waves

$$v_P(375m) = 3878 \pm 12 \quad m/s$$

$$v_S(375m) = 1975.8 \pm 8.0 \quad m/s$$

Attenuation length

Expectation: several kilometers ↔ Measurement: 300 m

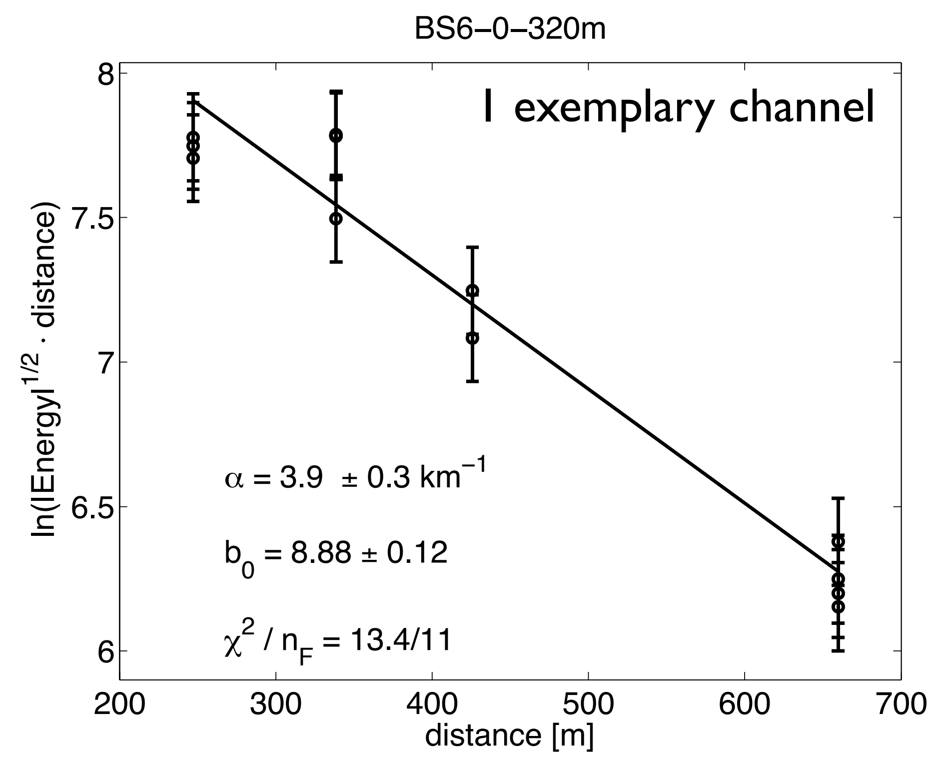
Analysis	α_{att} (km^{-1})
Pinger data (time domain)	3.20 ± 0.57
Pinger data (frequency domain)	3.75 ± 0.61
Inter-string data (same level)	3.16 ± 1.05
Inter-string data (3-level ratios)	4.77 ± 0.67
Transient events	3.64 ± 0.29

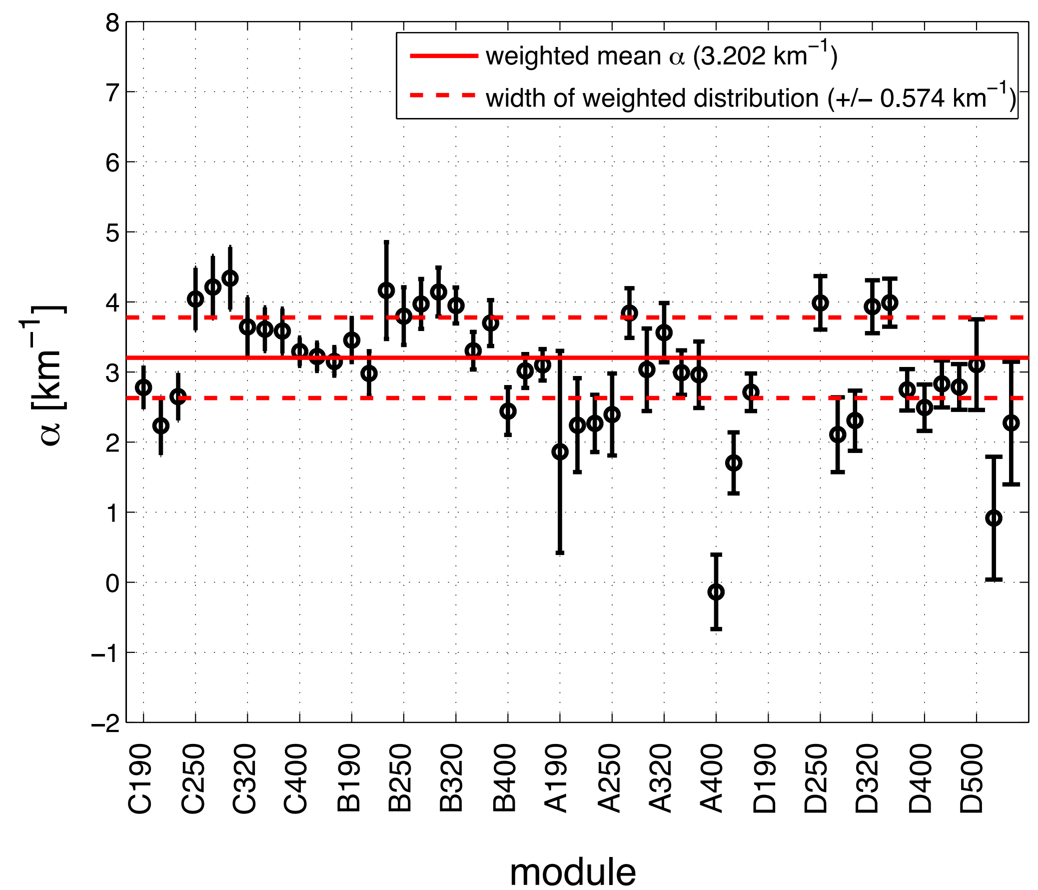
- No significant evidence for depth dependence, but not excluded
- Unclear frequency dependence: absorption or scattering? (analysis with new pinger data in progress)

Pinger attenuation analysis

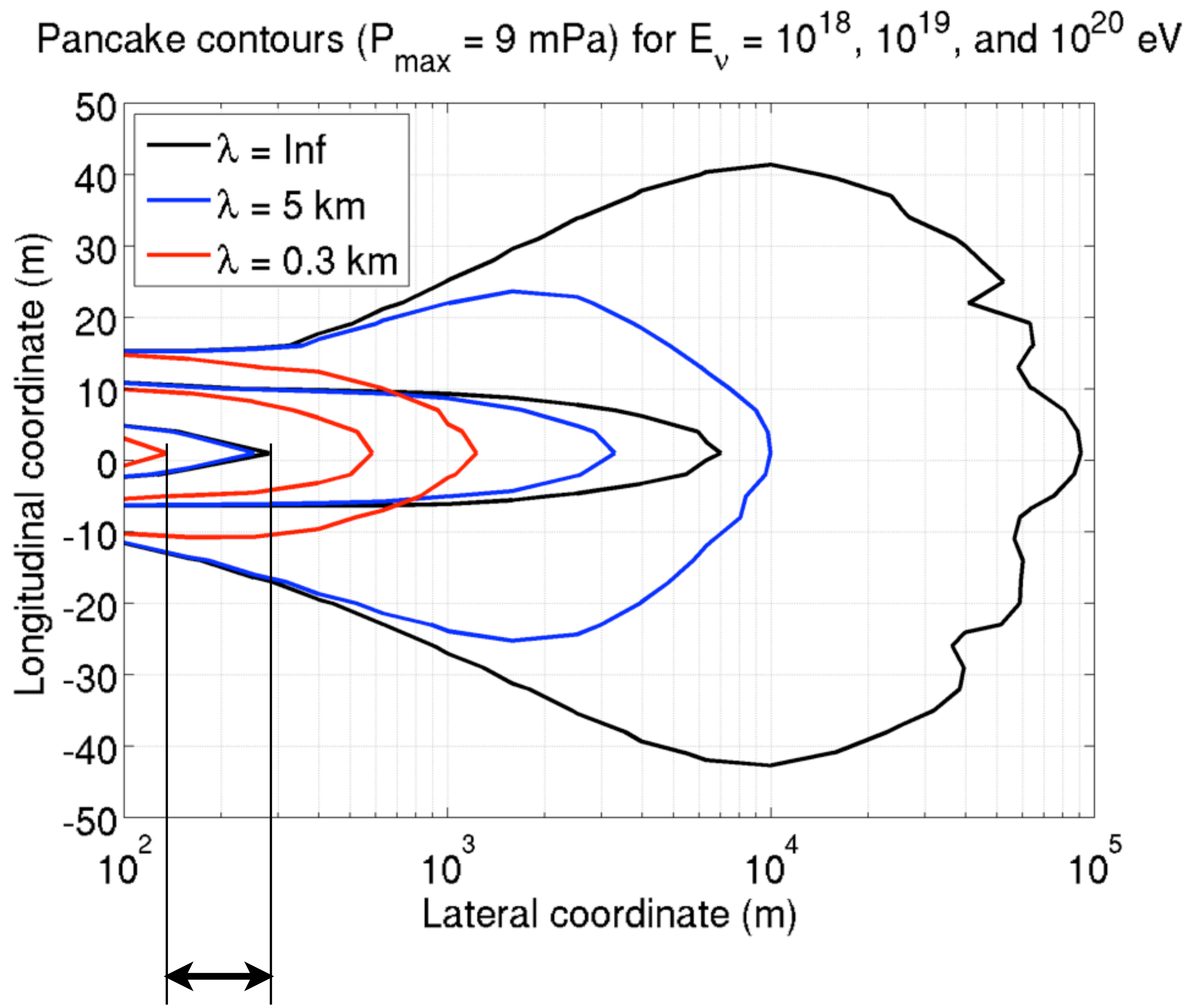
- Signal energy E calculated for each channel and over all pinger holes, noise subtracted from pinger-off runs
- Linear fit of y = ln (distance × $\sqrt{\text{energy}}$) yields attenuation coefficient α
- 48 independent measurements (sensor channels)
- Weighted mean value and width of distribution: $\alpha = 3.20 \pm 0.57\ \text{km}^{-1} \leftrightarrow$

  $\lambda = 312\ \text{m}^{+68\ \text{m}}_{-47\ \text{m}}$





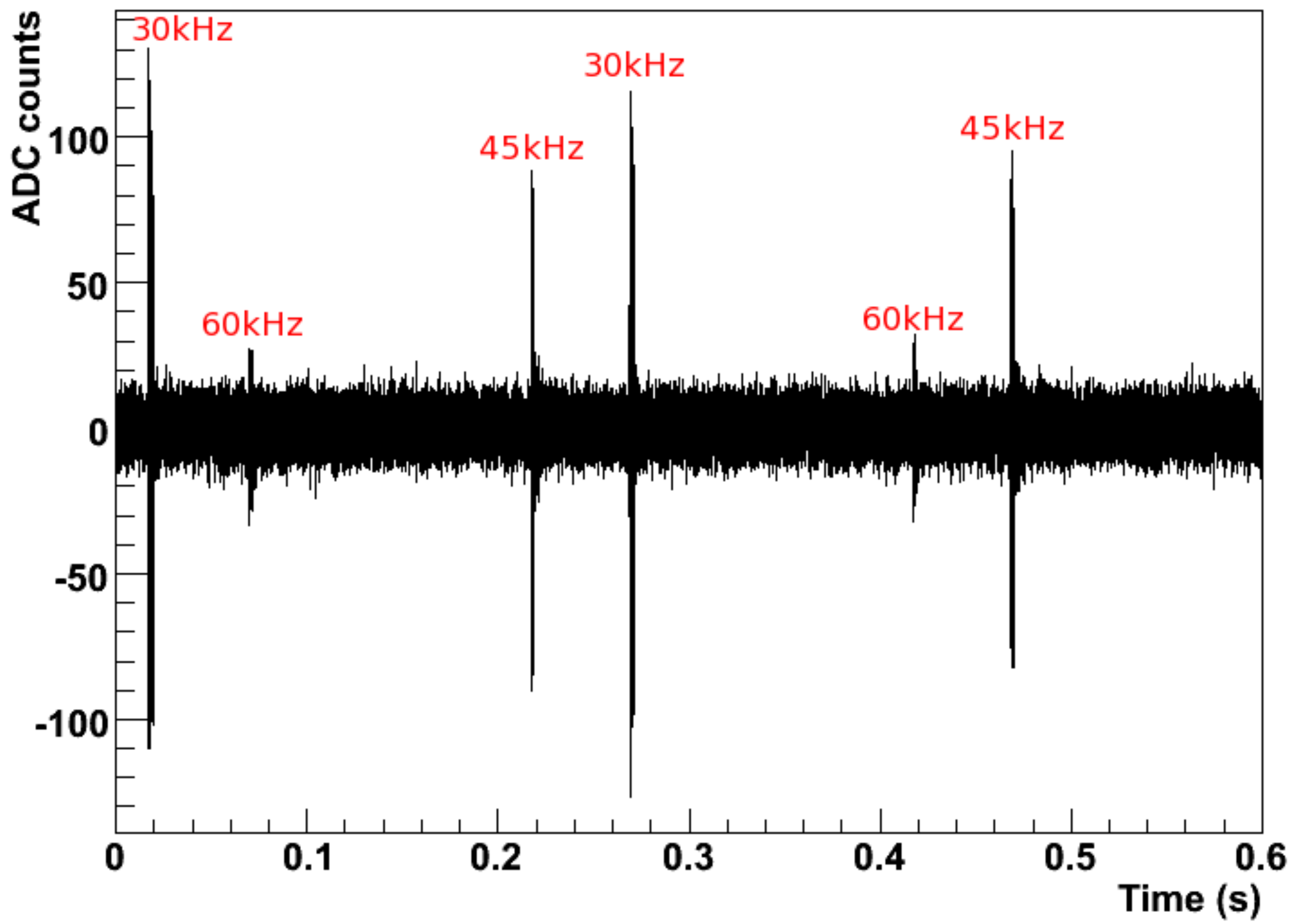
Implications of short attenuation length



@ 10^{18} eV: Loose Factor ~2 in "visibility range"

- Short attenuation length only relevant at high (> 10^{19} eV) energies
- At low energies (where expected flux is highest) 1/r decrease dominant

Further studies: The "multi-frequency" pinger 2009/10



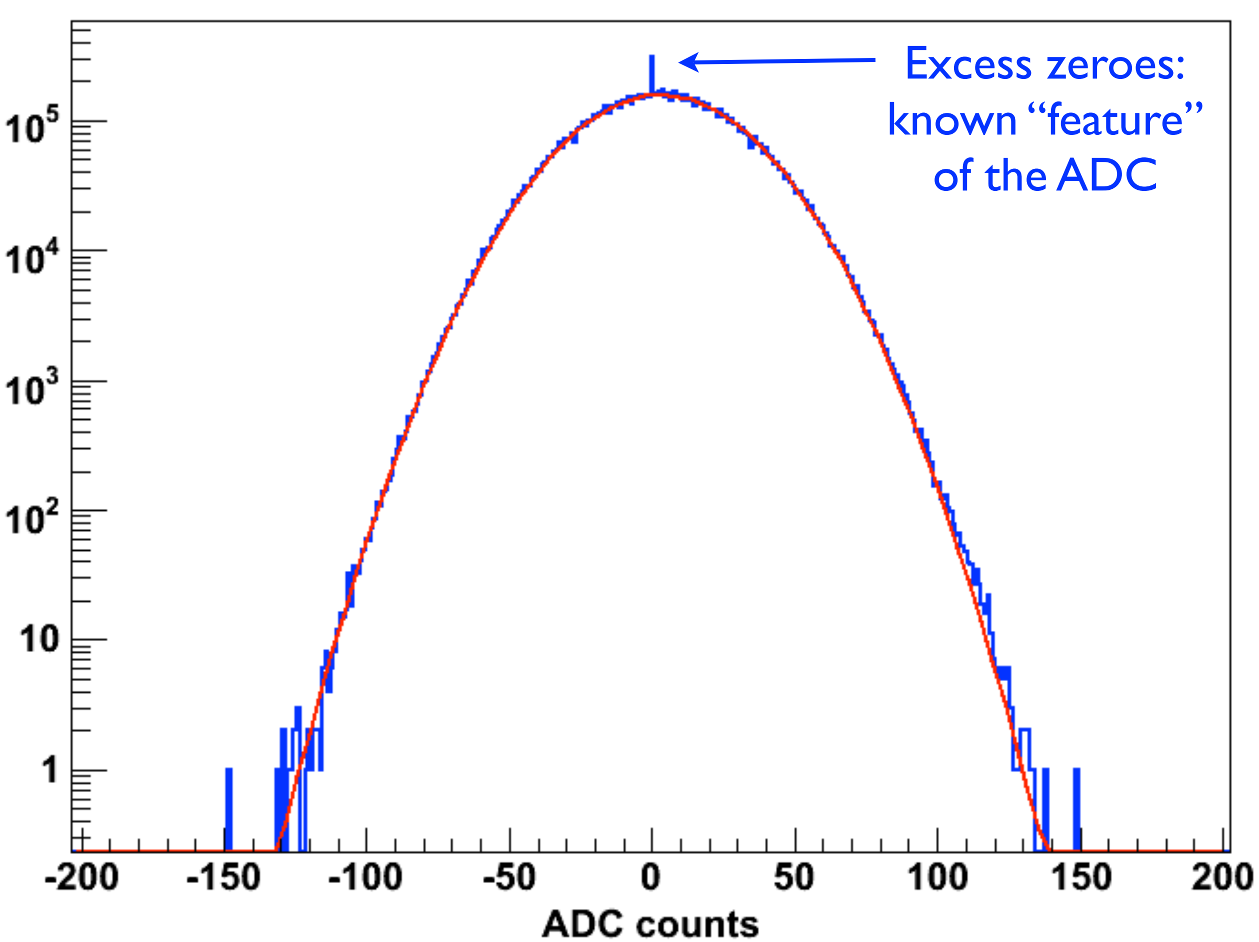
- Frequency dependence of attenuation length ⇒ attenuation mechanism
  - Absorption: frequency independent; Scattering: $\alpha_{att} \propto f^4$
- Deep stops (up to 1000 m) to measure sound speed and attenuation in deep ice and on inclined paths
  - Also interesting for Glaciology (ice crystal orientation)
- Data under study

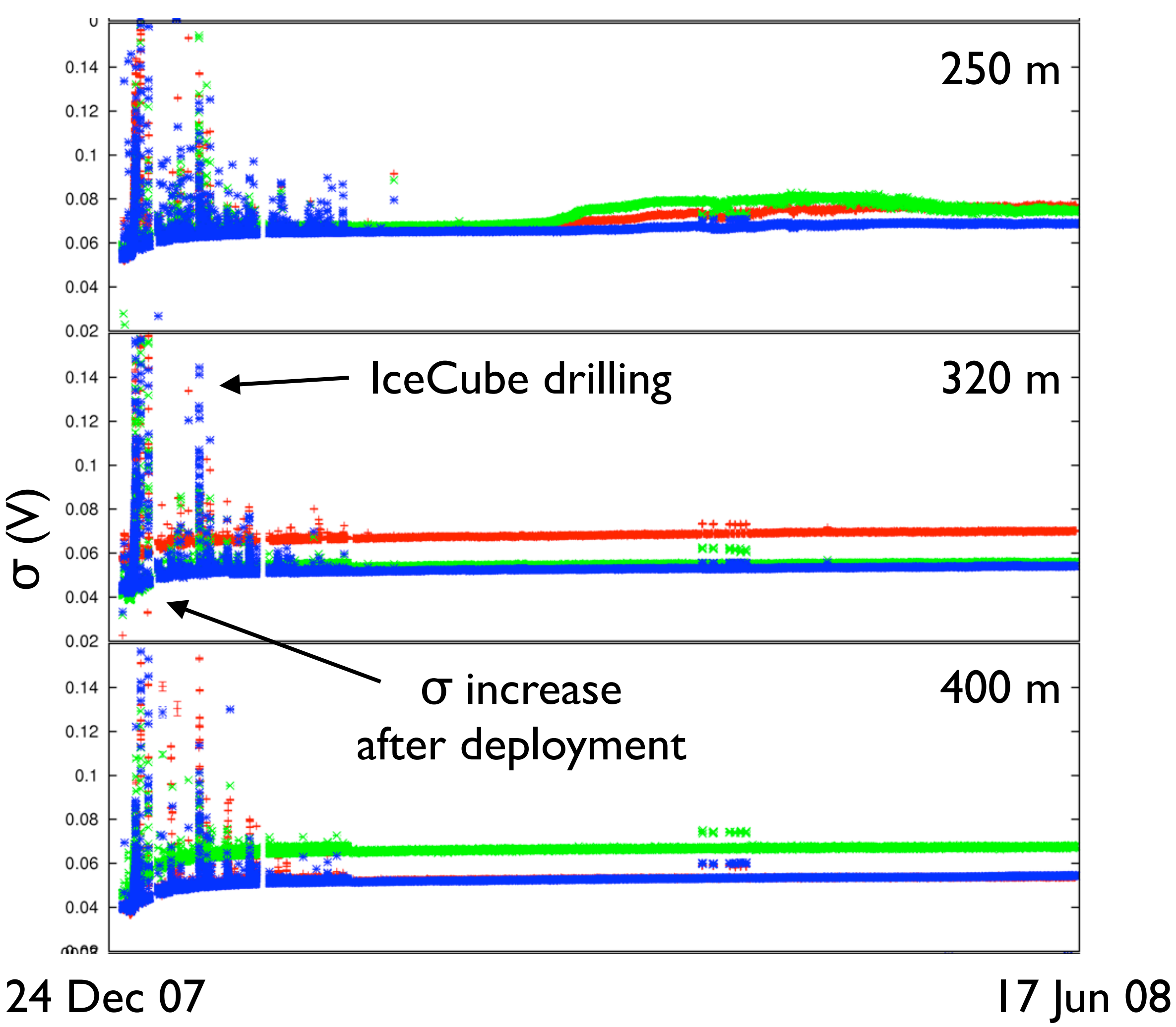
Absolute noise level & Sensor calibration

see also
poster on sensor calibration
(L. Paul et al.)

Noise: properties and temporal evolution

- Gaussian and stable over long time
- Peaks correlated with IceCube drilling, inter-string data taking
- Hypothesis: freeze-in improves coupling to ice causing noise level to increase and then stabilize in the first couple months





Absolute noise level

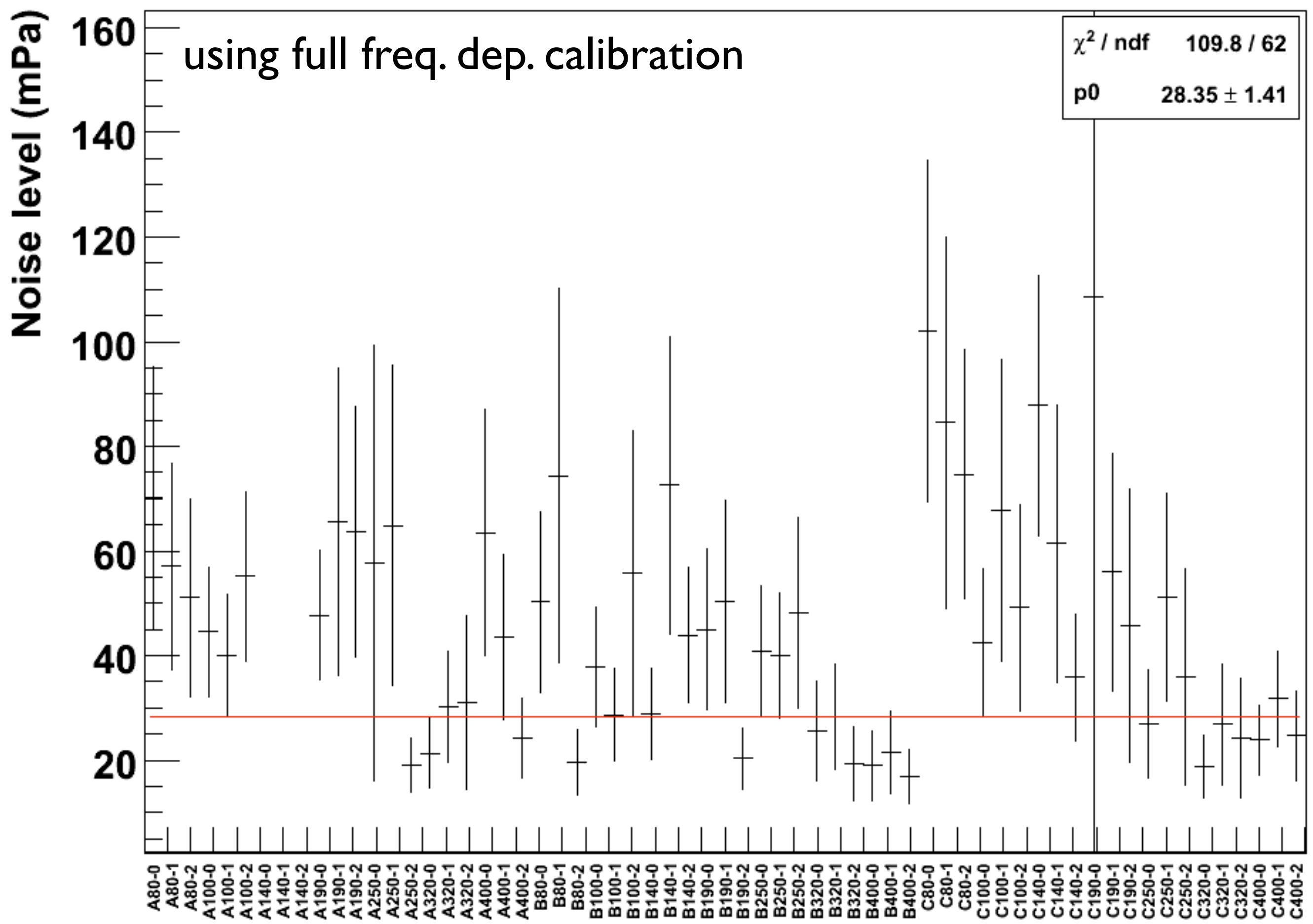
- SPATS sensors have been calibrated in water at 0℃ prior to deployment (relative to a reference hydrophone SensorTech SQ-03)
- In-situ calibration is challenging, but
  - Can study different effects separately in the lab
  - Temperature −50℃:
    - sensitivity increase by factor 1.5 in air
  - Increased static ambient pressure:
    - sensitivity stable within 30% in water at room temperature
  - Different coupling from medium to sensor (acoustic impedance)
    - under study (cf. calibration poster)

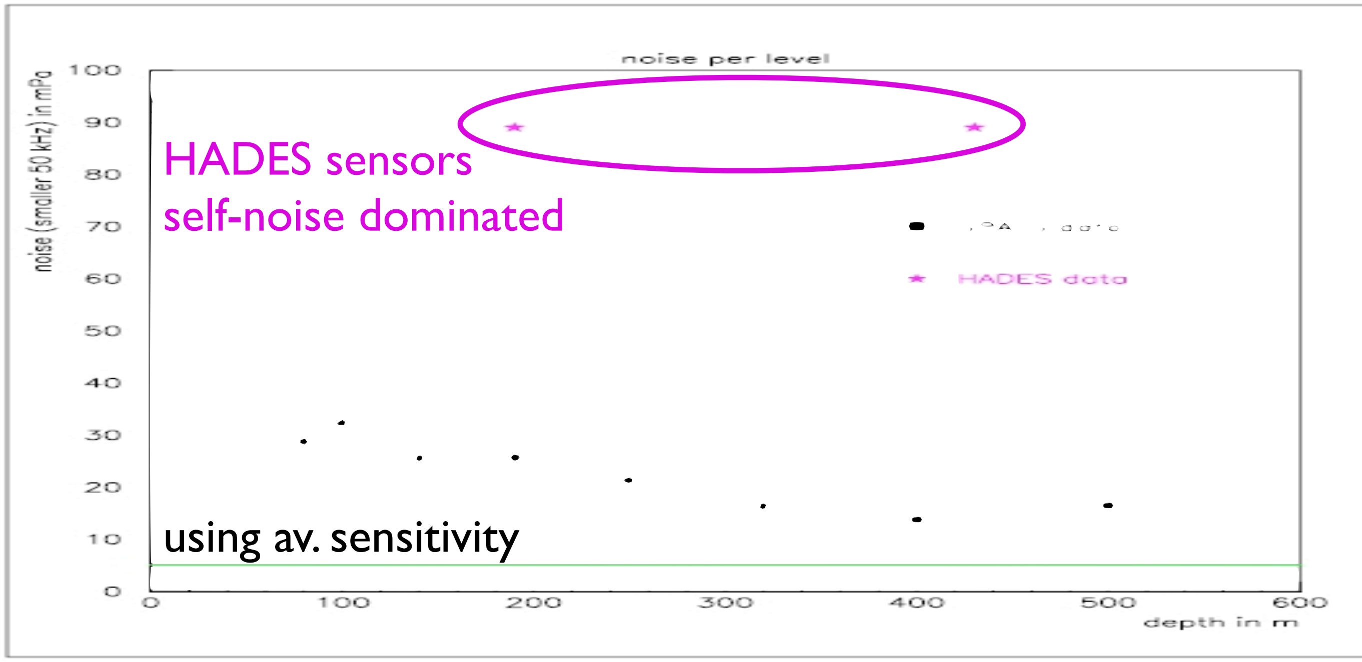
Wuppertal Water Tank
11 m^3 water

Aachen Ice Tank
3 m^3 bubble free ice

Uppsala Pressure Vessel
liquid filled,
cable feeds,
up to 1000 bar

Estimation of absolute noise level (10 – 50 kHz)



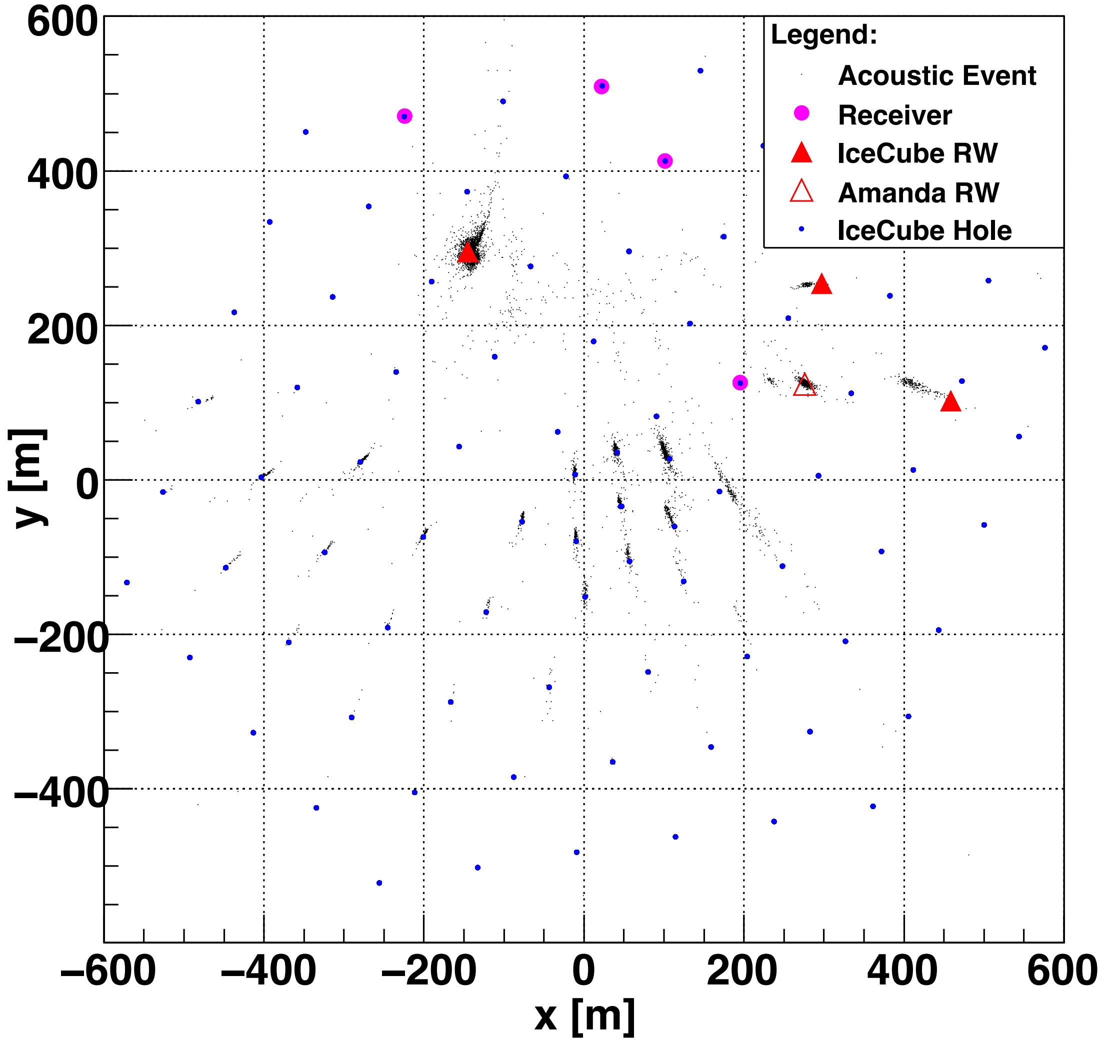


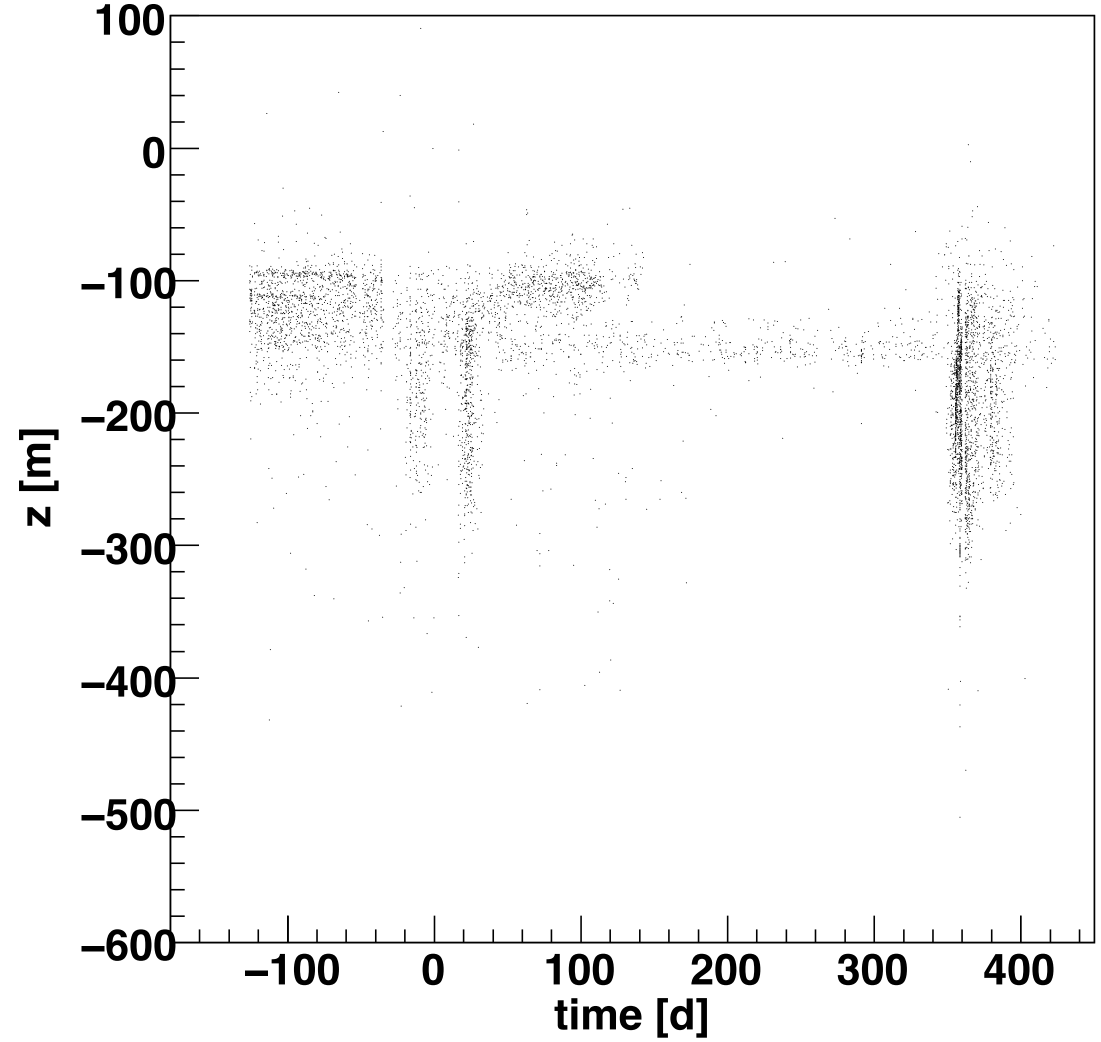
- Use sensitivity correction factor of 1.5 (from temperature)
- Sensitivity change due to freeze in under study
- Different approaches agree within a factor of 2
- In-situ measurement with different type of low noise glaciophone planned for 2010/11 season

Transient sources
&
Event reconstruction

see also
talk on SPATS sensitivity
(J. Berdermann)

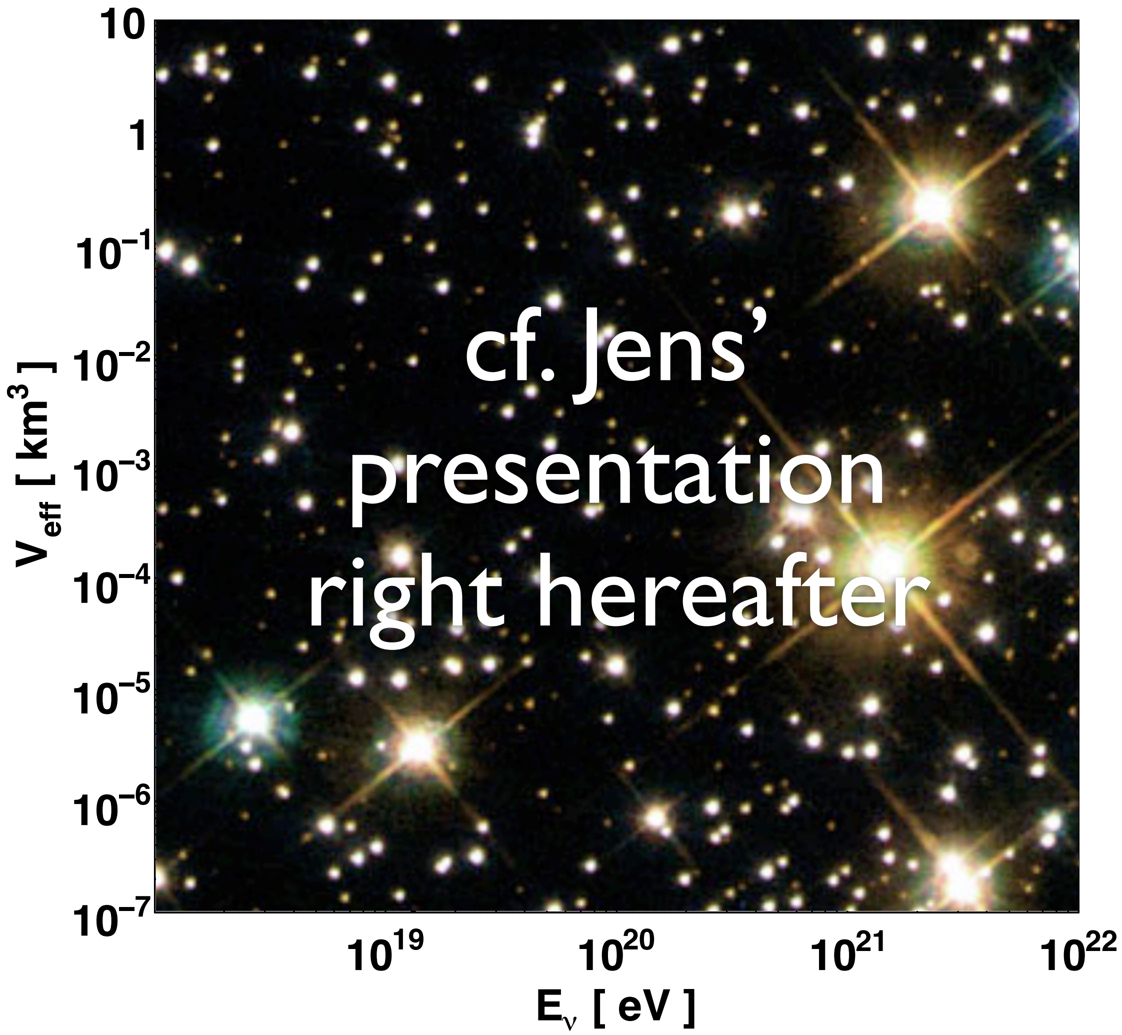
Spatial and temporal distribution of vertices

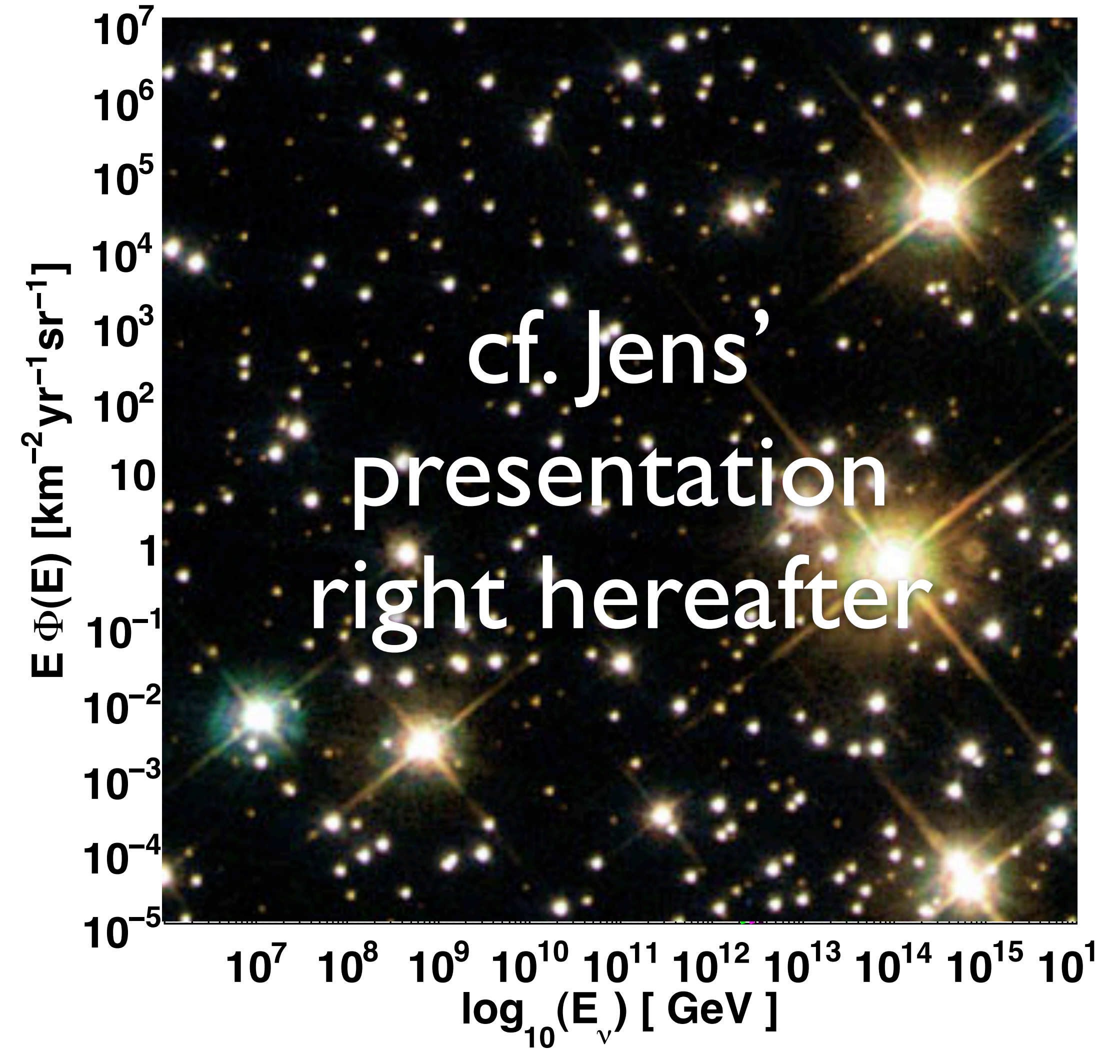




- Transient data recorded for 45 minutes of every hour
  - nearly 2 years of data available
- Only shallow (top 200 m) transients observed outside IceCube drilling
- Refreezing of close IceCube holes and Rod-wells are main (only) sources

SPATS sensitivity

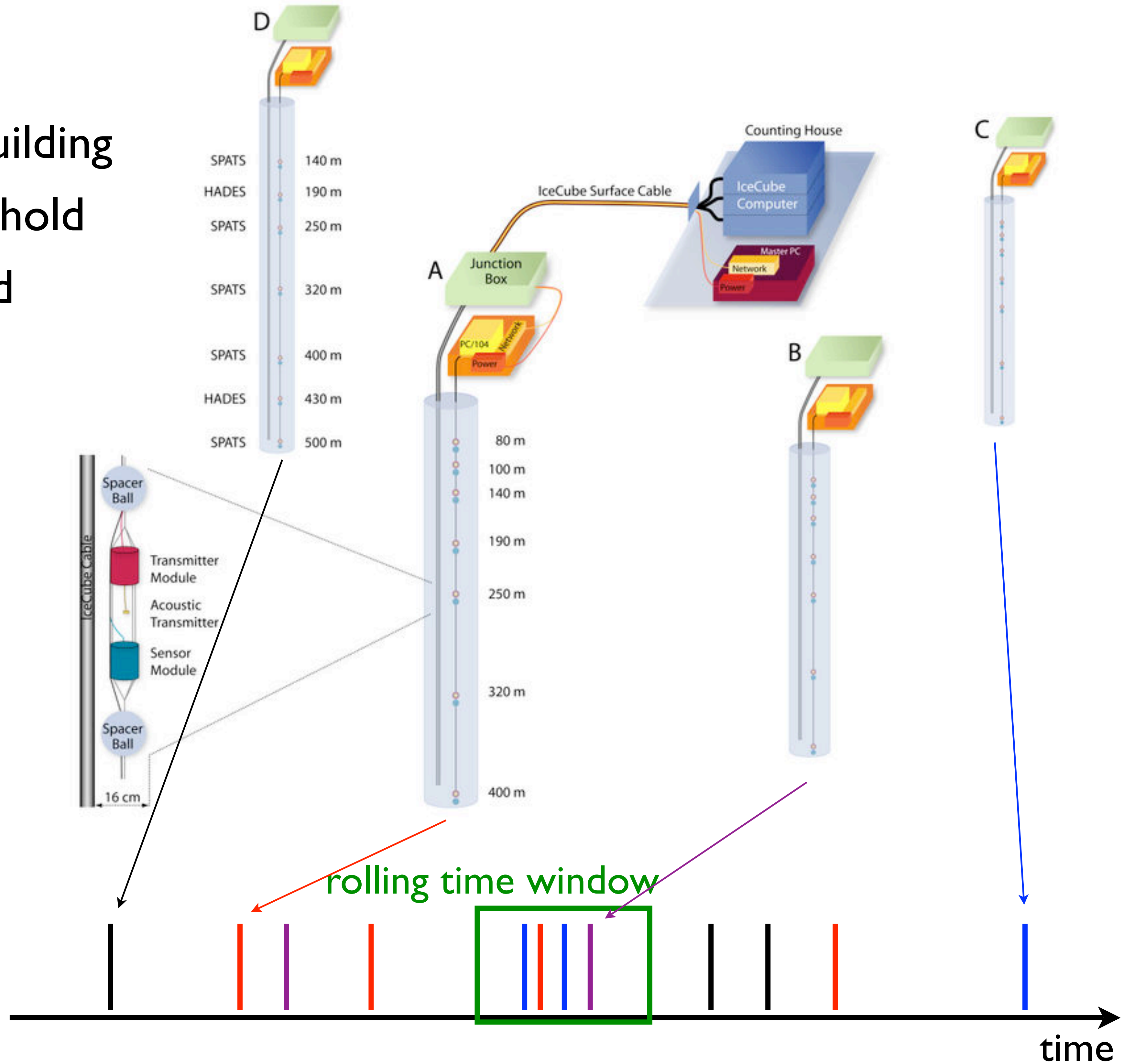




- Simulate ν interactions outside IceCube volume and below 200 m (no refraction)
- Trigger threshold 50 mPa (estimated)
- Very promising result for a test setup

DAQ software upgrade

- Online coincidence building
  - lower trigger threshold
- Currently being tested at South Pole



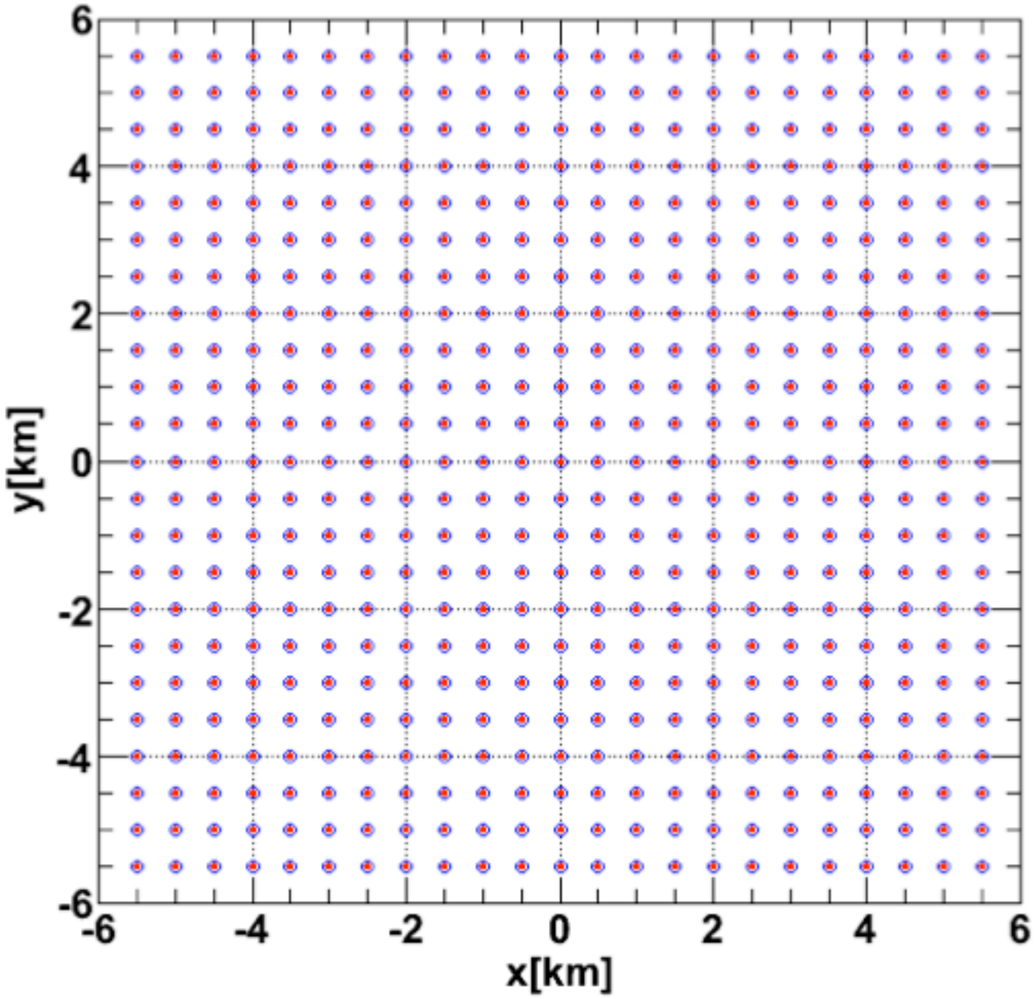
Implications for acoustic neutrino detection at South Pole

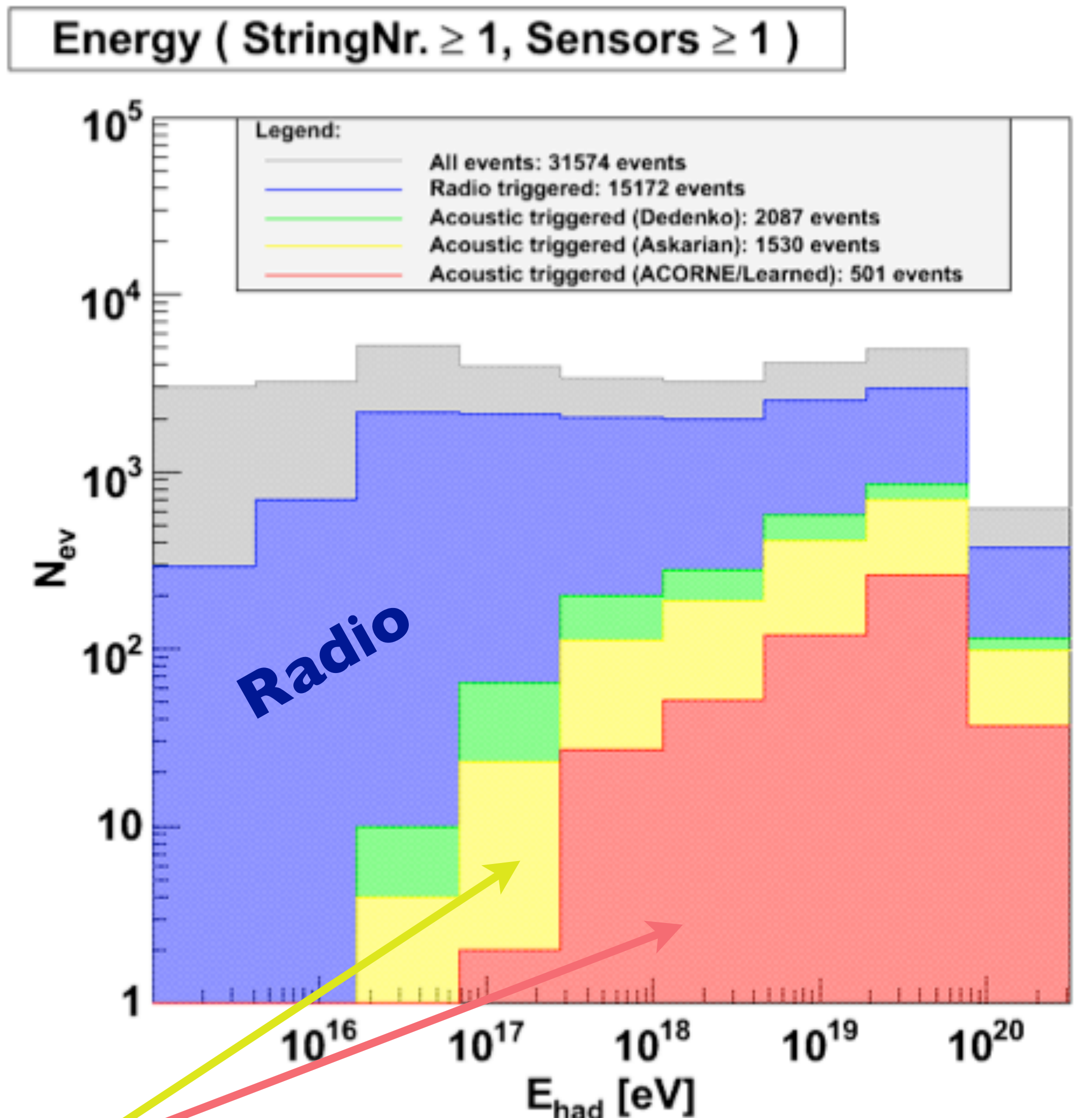
Implications for acoustic neutrino detection

- If acoustic noise level is low:
  - low noise sensors can compensate for short attenuation
- Acoustics can add valuable additional information in hybrid neutrino detector (e.g. in combination with radio)
  - reduce systematic uncertainties
  - increase confidence in signal in absence of calibration beam (e.g. atmospheric muons / neutrinos in optical neutrino telescopes)
- Possible scenario:
  - at "low" energies: use radio for triggering: signal in single acoustic sensor significant
  - at "high" energies: separate(?) acoustic trigger: use hybrid information for direction/energy reconstruction

Possible radio/acoustic hybrid scenario

25 km², string spacing 500 m (441 strings)
8 acoustic sensors between 200 m and 300 m





J. Berdermann, M. Carson, R. Nahnhauer, IceCube internal note (2009)

Radio/acoustic conicidences

Detection Mode	Trigger	Learned	Askaryan
1Sensor	Radio	3%	10%
4Sensors (1 String)	Acoustic	1%	5%
4Sensors (3 Strings)	Acoustic	0.1%	3%

Acoustic GZK events / year

	Learned	Askaryan
ν_μ	0.4	1.7
ν_e	0.2	0.8
Total	0.6	2.5

Aim of SPATS: Mission nearly accomplished

- Speed of sound and Refraction
  - speed of sound constant below 200 m
    no refraction
- Attenuation length
  - $\lambda \approx$ 300 m (20% uncertainty), factor 30 smaller than expected
    possible explanation: larger influence of scattering
  - frequency and depth dependence under investigation
- Noise floor
  - Gaussian and stable
  - Comparable to deep sea (with reasonable assumptions)
    better results soon to come
- Transient noise
  - Small rate and all deep events from identified sources

Open questions and Plans

- Absolute noise level
  - Deployment of low noise sensor pre-calibrated in ice planned for 2010/11
- Study mechanism of surprisingly short attenuation length
  - Interest from Glaciology community
  - Data available from "multi-frequency" pinger

➡ Have robust sensitivity estimate for acoustic technique at South Pole within next 12 months