South Pole Acoustic Test Setup

Calibration and lake test

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Outline

1) The SPATS project
   - Goals
   - Setup
2) Sensor and transmitter calibration
   - Hydrophone calibration
   - Sensor calibration
   - Transmitter calibration
3) Frozen lake long-range test
   - Goals
   - Setup
   - Results
     - Transmitter range
     - Variations between transmitters
     - Sensor directional information
4) Summary

Goals

Acoustic neutrino detection array ~> acoustic properties of the South pole ice ?

=> Absorption lengths
=>Horizontal spacing of strings

=> Speed of sound
=> Refraction of surface noise

=> Background noise level
=> Energy threshold

=> Transient events
=> Locate sources of background events

- Variation of critical parameters is expected to be strongest.
- Lowest temperatures = optimal for acoustic neutrino detection.

⇧

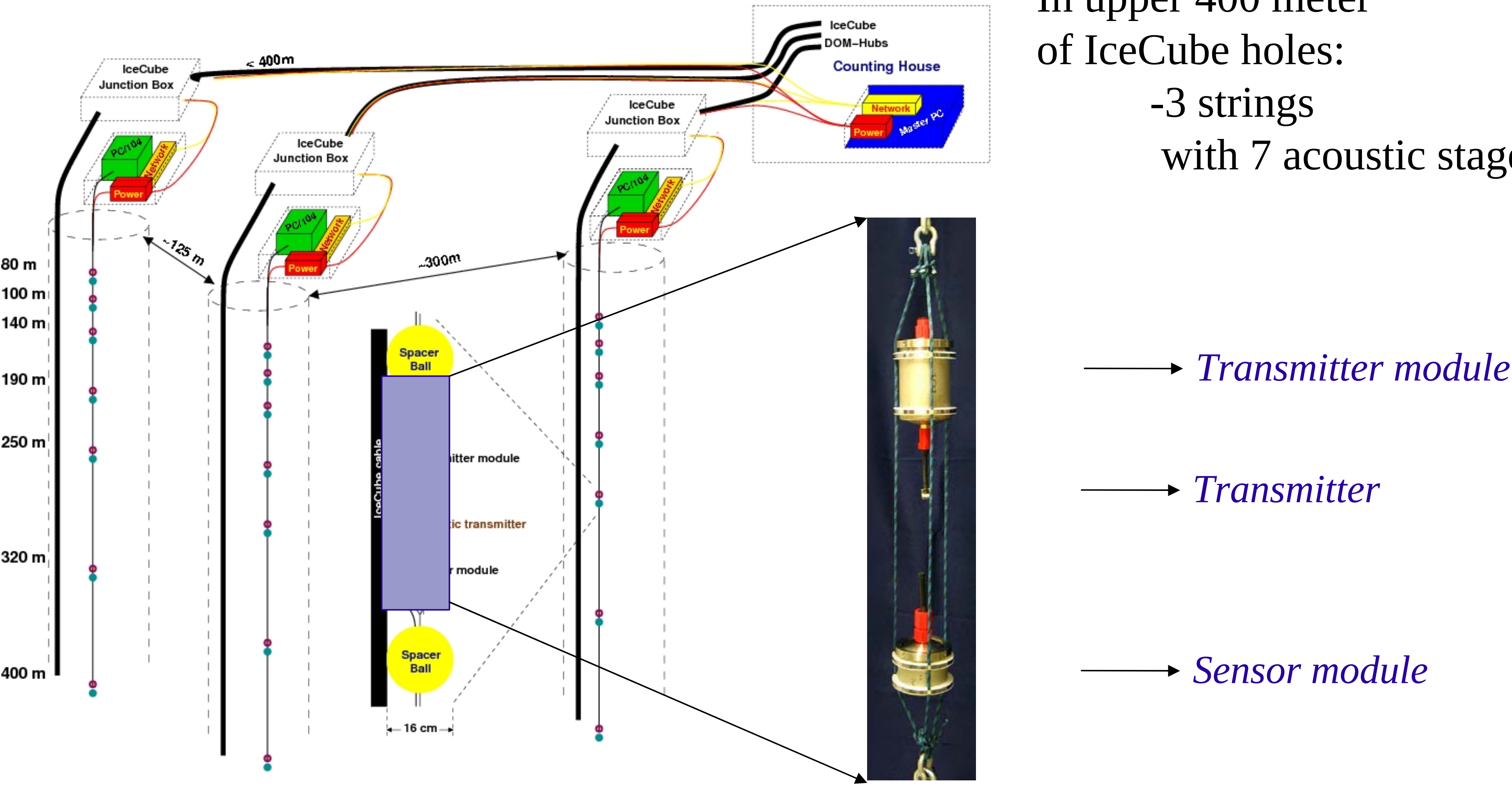
Deploy powerful acoustic transmitters and sensors in first 400m of the ice sheet.

⇩

Use upper part of IceCube holes!

Setup: in-ice devices

In upper 400 meter of IceCube holes:
- -3 strings with 7 acoustic stages



=>25 stages have been build and calibrated.

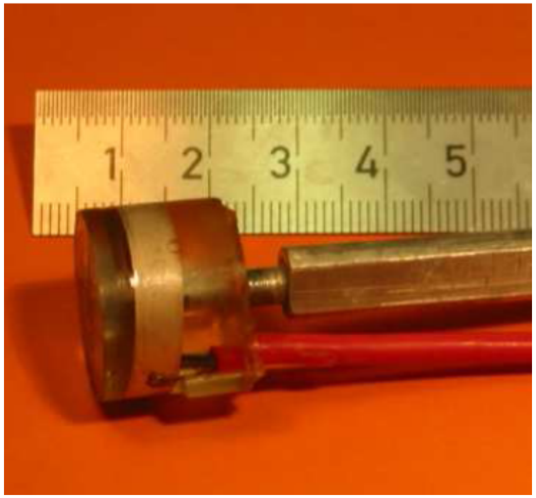
Setup: transmitter

-HV pulse generator

- 1kV@10μs
- L/C circuit
- Pulse read back system

-Auxiliary T/P sensors

⇒Shape and stability of the pulse?
⇒T-dependence of the pulse amplitude?



-Ring shaped piezo ceramics

- Generates broadband pulse
- Azimuthal isotropic emission

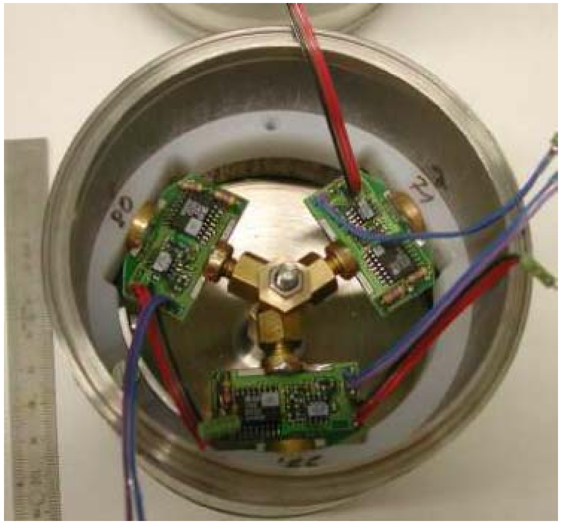
-Cast in epoxy

⇒Sound production efficiency?
⇒Radiation behavior in far field?
⇒Azimuthal and polar variations in emission?

Setup: sensor

- 3 channels = 3 piezo ceramics

- d33 has been determined for each piezo ceramic
- d33 = (Q / F) along axis of polarisation

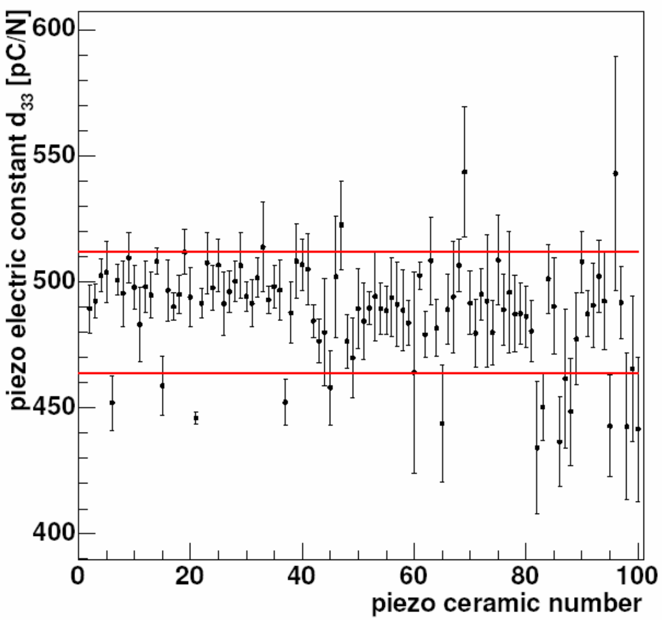


- Mechanical contact

- Preload screw =>Press the piezos against steel housing

-Low noise 3-stage amplifier board

-Voltage regulation board



⇒Complex system with many different materials
- ⇒Different preloads?
- ⇒Resonances?
- ⇒Frequency dependence of the sensitivity?
- ⇒Equivalent self noise?

⇒Every complete sensor is different

→ need to be calibrated individually

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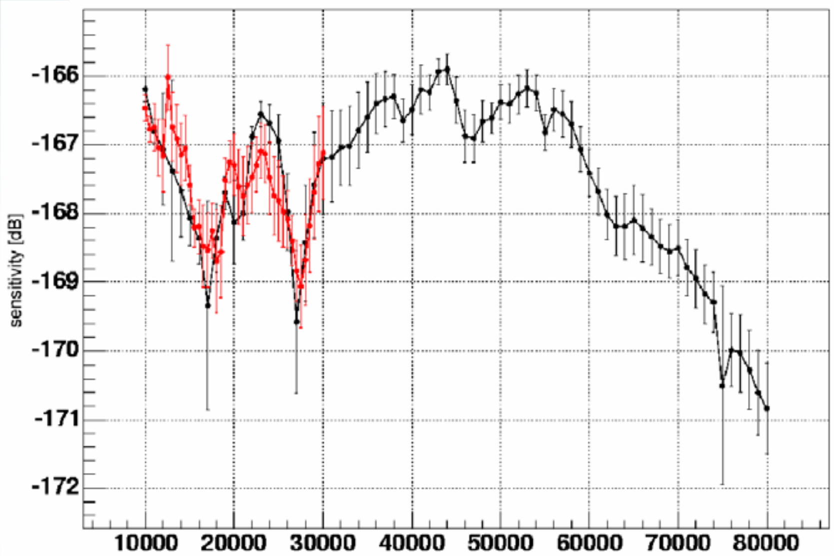
Hydrophone calibration

Sensortech SQ03

- Broadband: 1Hz – 65 kHz
- Stable: ΔC = 0.33%/˚C

Nominal Sensitivity:

-163.3 ± 0.3 dB re. 1V/μPa

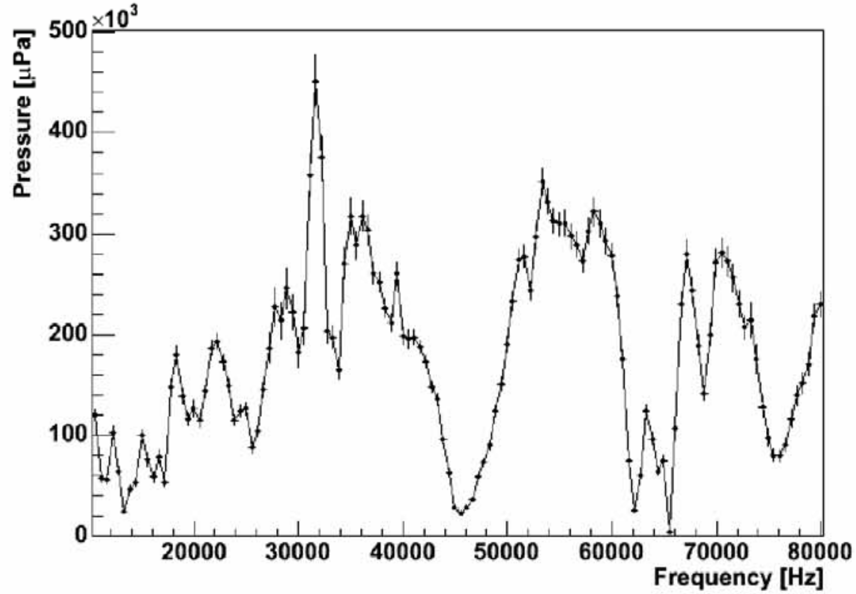


Recalibration:

- IDAC, Rome
  (Thanks to Silvano Buogo)
- after 3 years

  -167.5 ± 1 dB re. 1V/μPa

  ➔ **- 38% Sensitivity**
- rather flat from 10kHz-80kHz



➔ Transmitter pressure spectrum

Setup

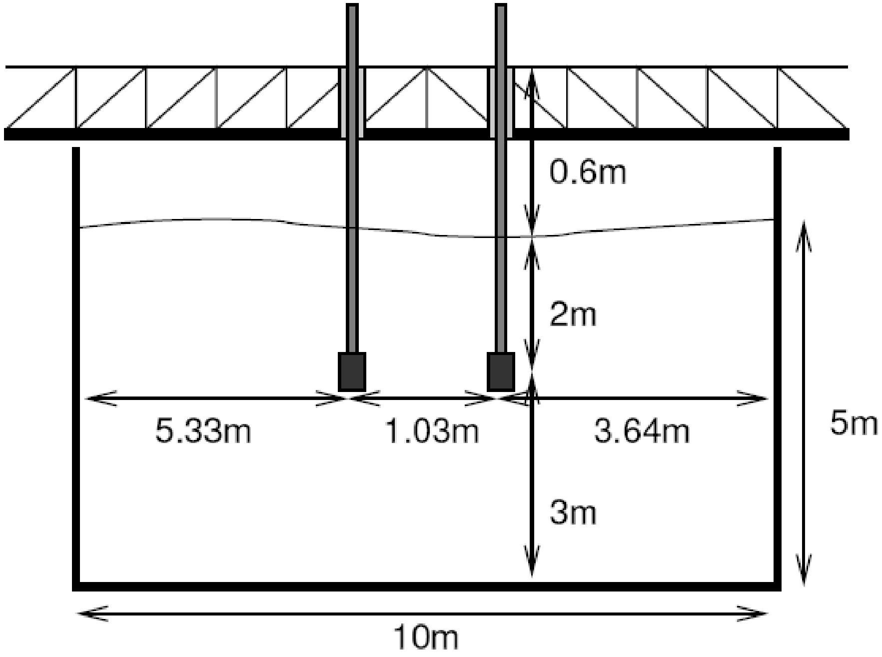
For sensor calibration, we need:

a) Sufficiently large water tank

=> no interference with the direct signal

→ HSVA

"Hamburger Schiffbauversuchsanstalt"



78m x 10m (2 depths : 5m/2.5m)

Sensor calibration

Setup

For calibration, we need:

a) Sufficiently large water tank

=>no interference with the direct signal

→ HSVA
"Hamburger Schiffbauversuchsanstalt"

b) Broadband pulses

=>wide frequency range

→ HV pulses applied to ring-shaped piezo ceramic

c) Reference hydrophone of known sensitivity

=>obtain pressure spectrum of the broadband pulse

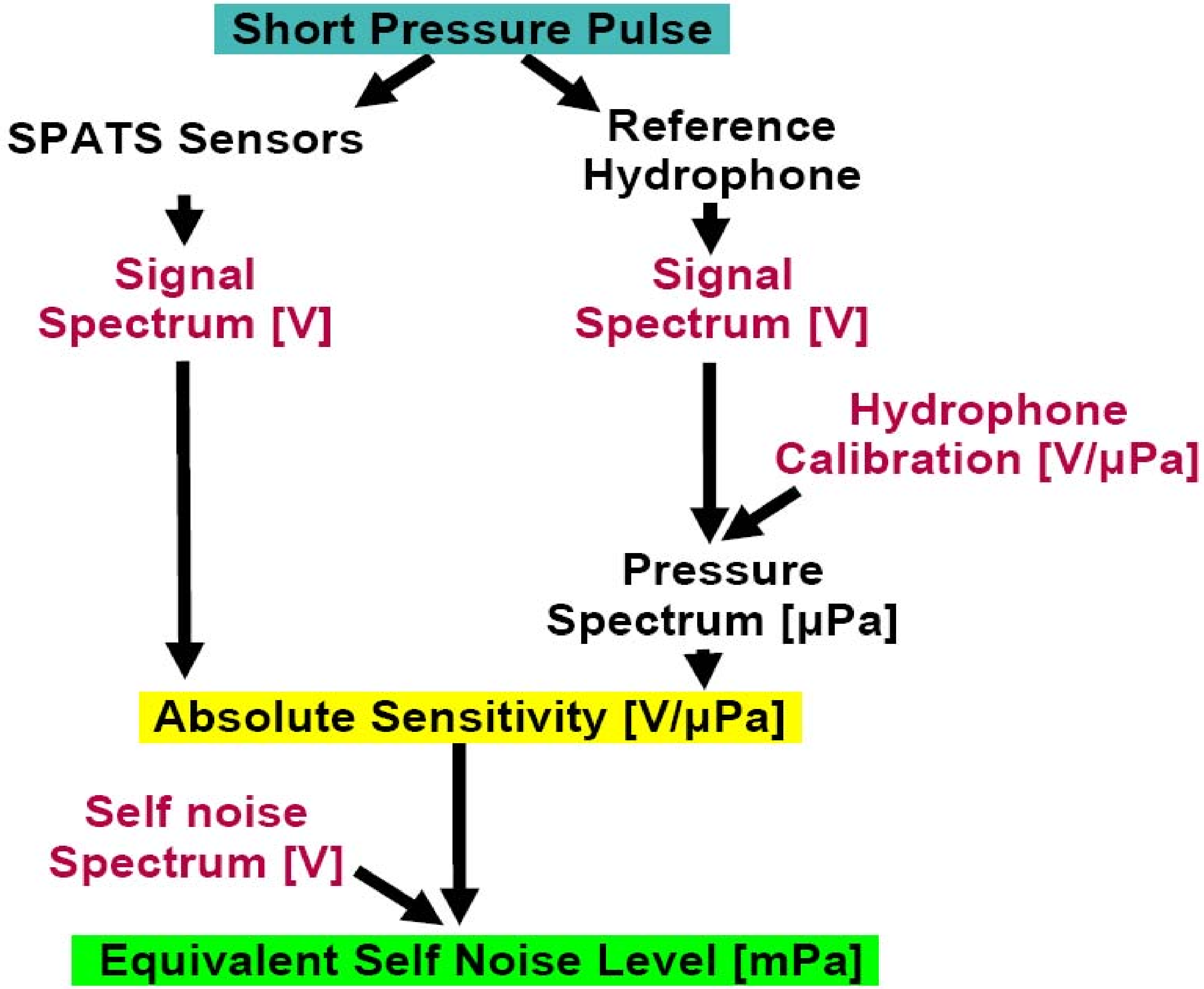
→ 

Has been calibrated to obtain sensitivity spectrum

=> signal spectrum [V]+ sensitivity spectrum [dB re V/μPa] => Pressure spectrum [μPa]

Sensor calibration

Method

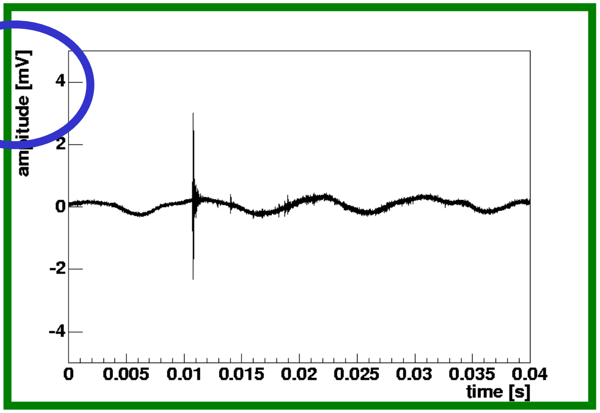


Sensor calibration

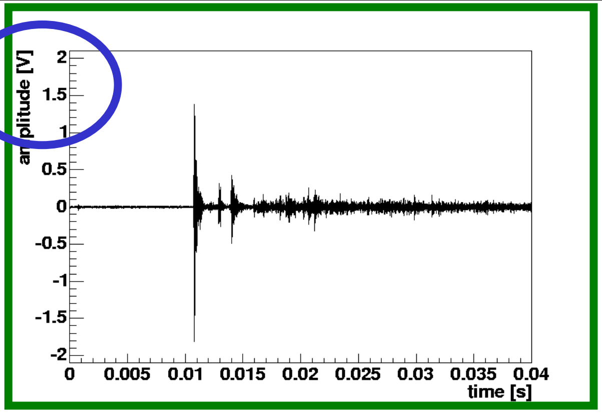
Results

Hydrophone signal

scale!

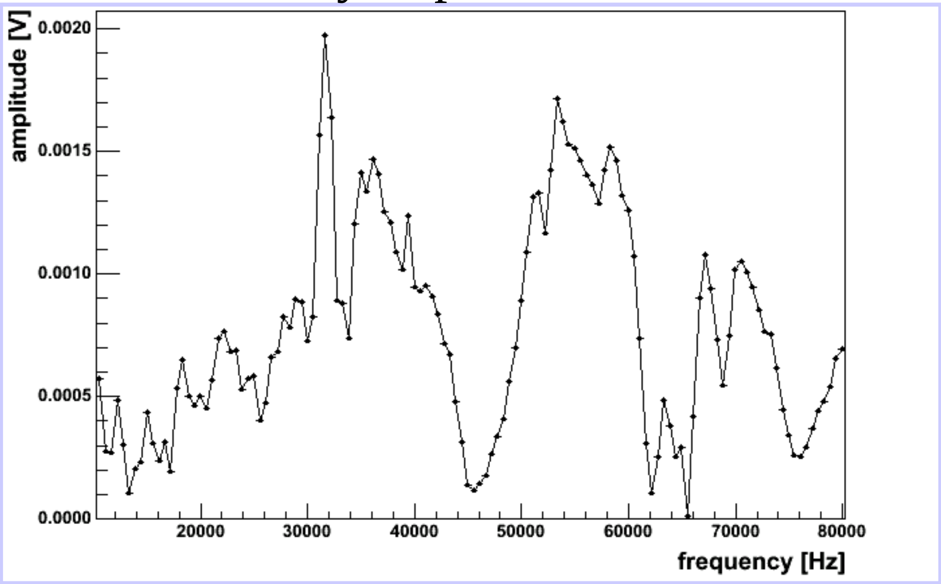


SPATS-Sensor signal for one channel

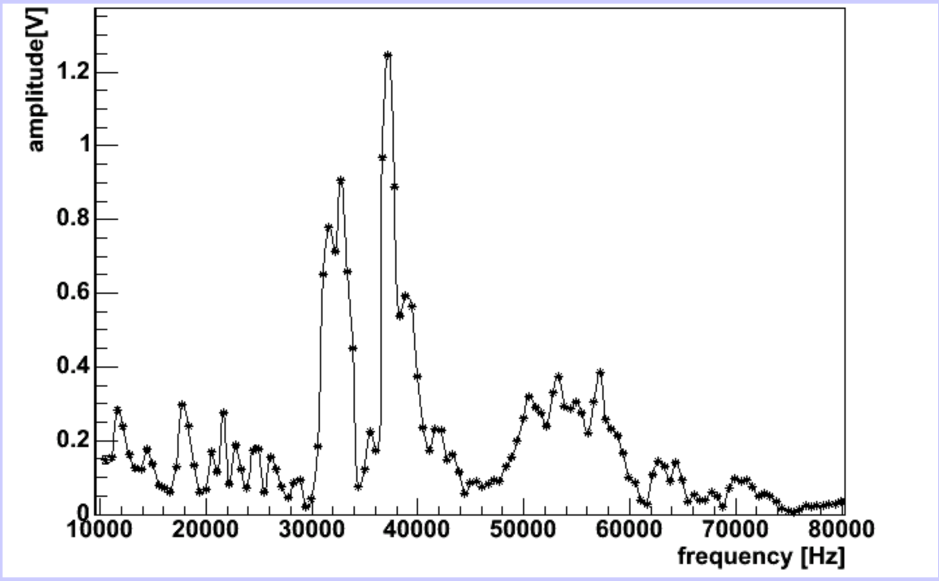


Spectra for the signals [V]

Hydrophone



SPATS sensor 25



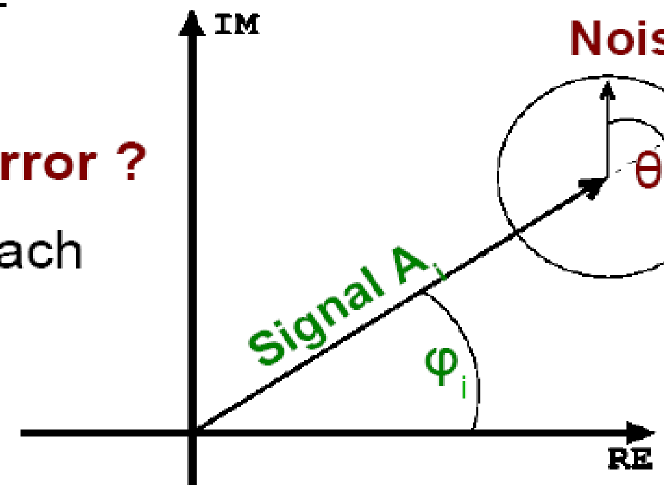
Results: errors

Problem:

- Avg. of events ➔ DFT ➔ **Noise reduced, Error ?**
- DFT ➔ Avg. of events➔ needs 2-dim approach

$$F(\omega)=\frac{1}{2\pi}\sum_i A_i(\omega_i)\cdot\exp(i\phi_i(\omega_i))+N_i(\omega_i)\cdot\exp(i\theta_i(\omega_i))$$

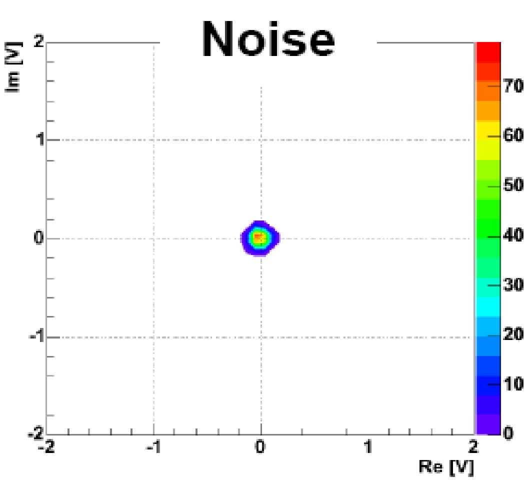
const random

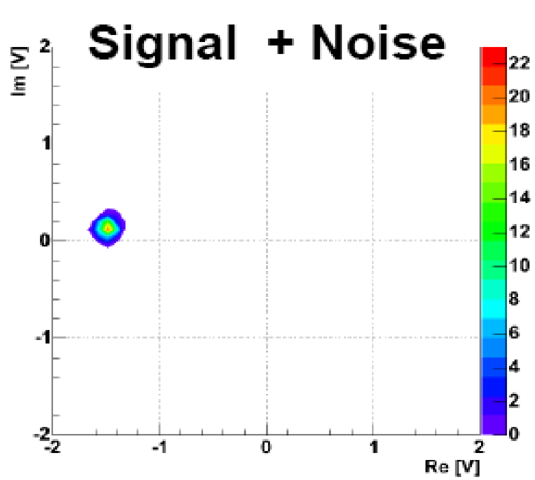


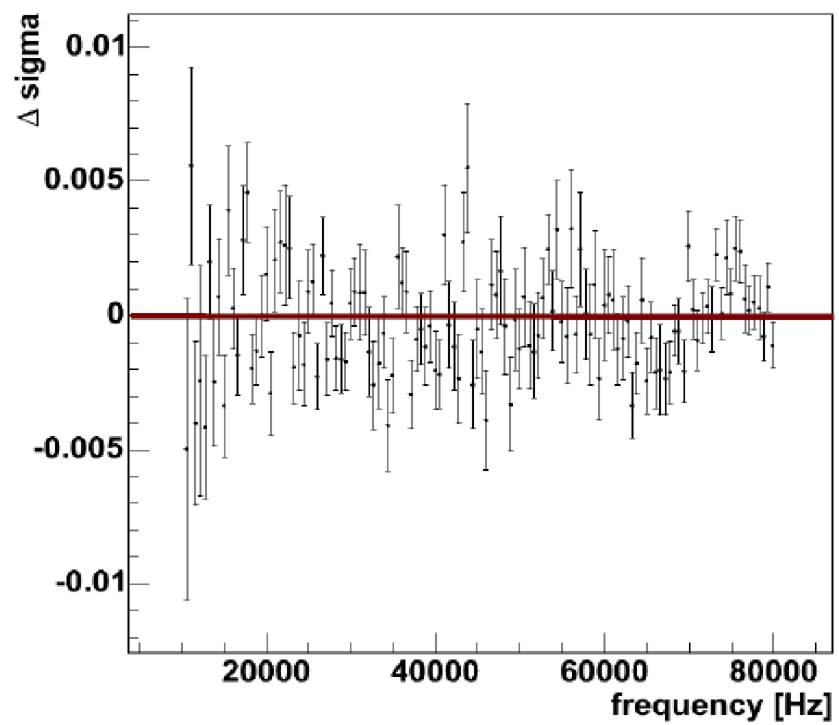
Comparison with off-signal:

➔ no additional contribution

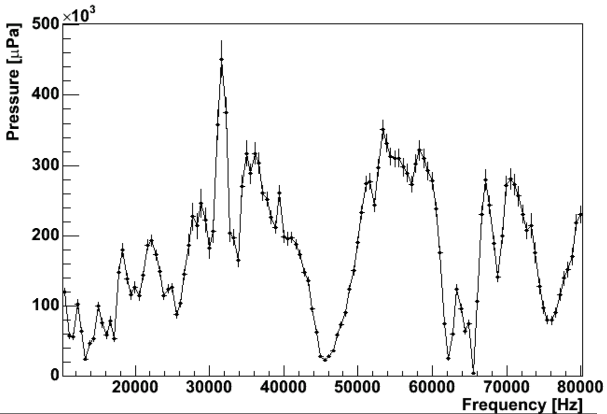
➔ uncertainty in central value as error





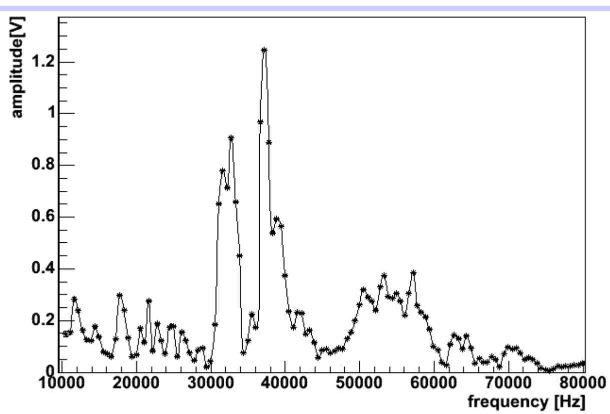


Results

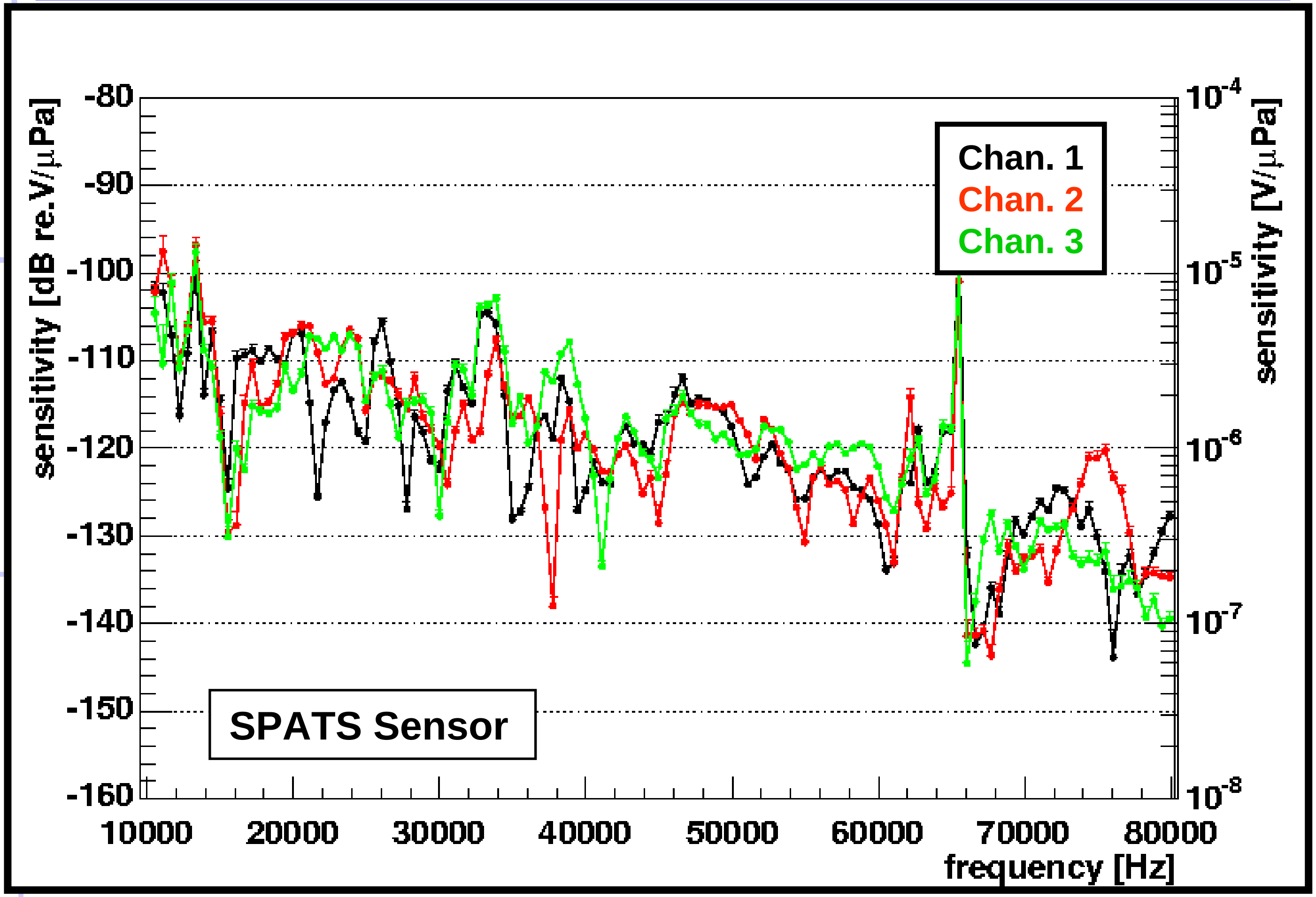


Pressure spectrum [μPa]

Spectrum for SPATS-Sensor Signal [V]

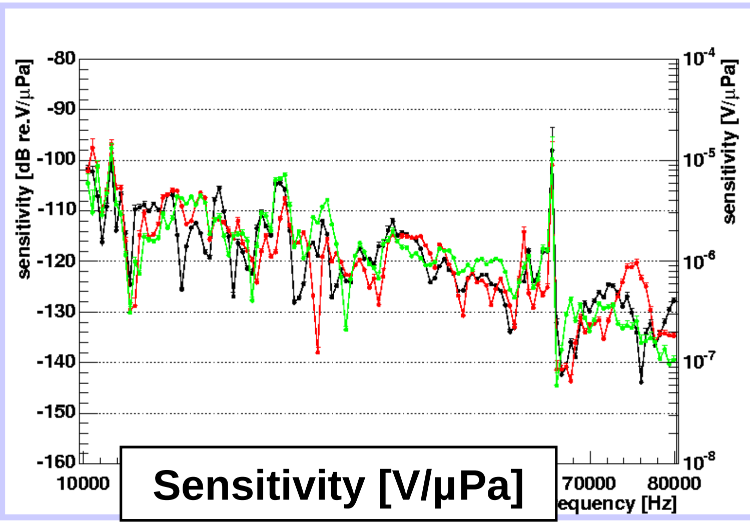


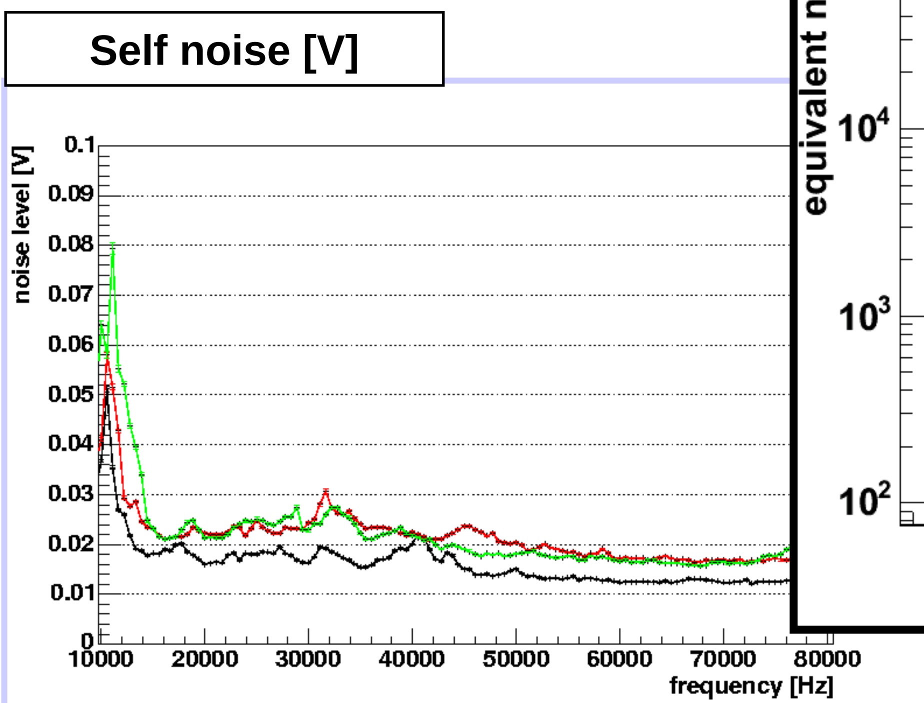
Absolute Sensitivity [V/μPa]

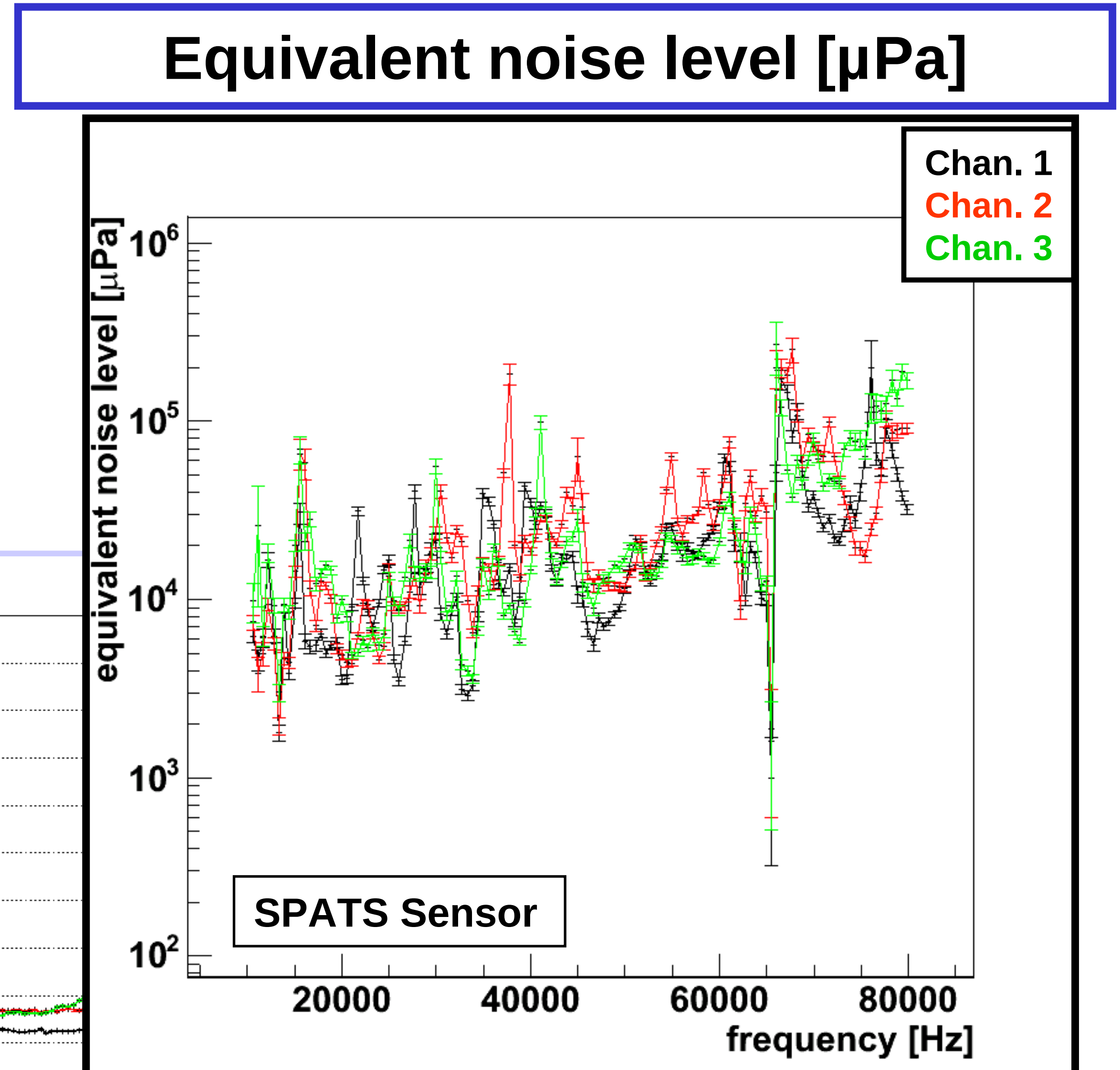


Sensor calibration

Results

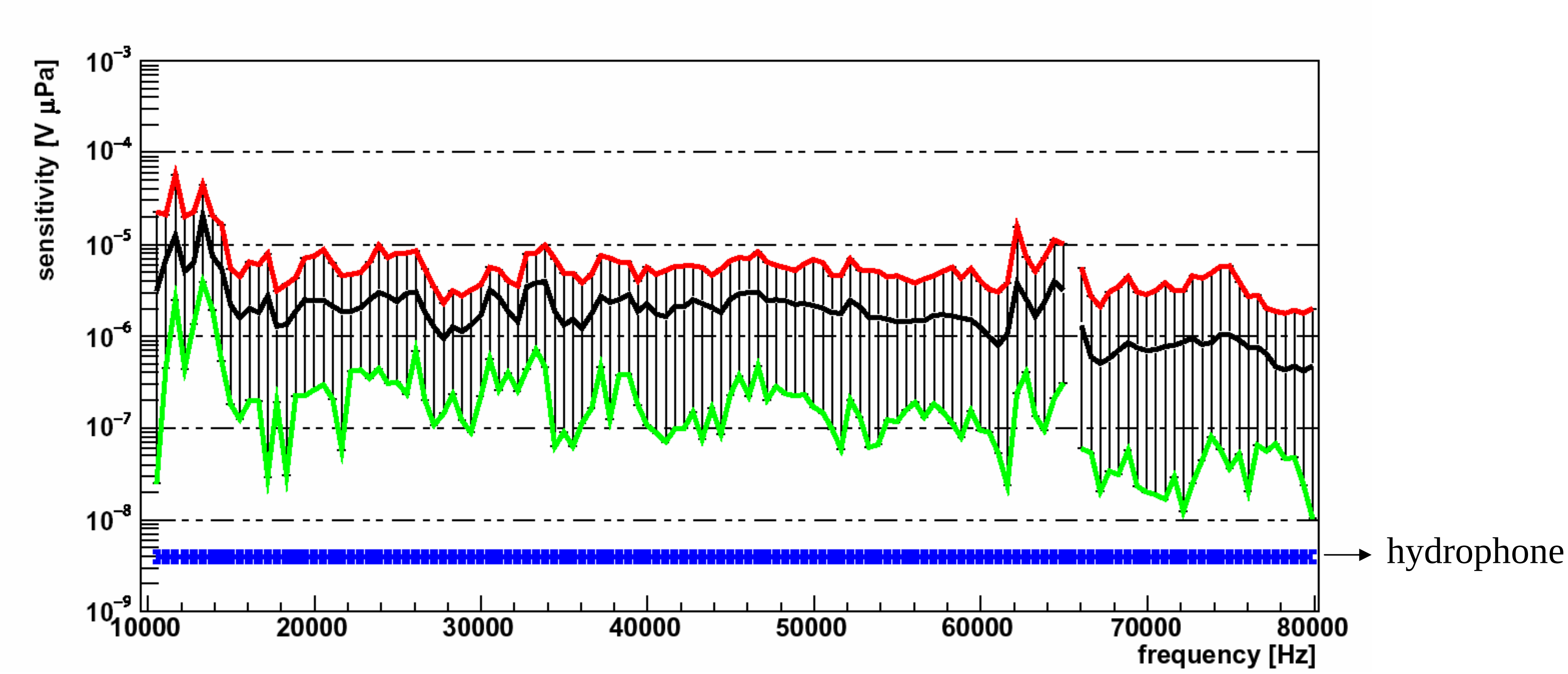






Results: overview for all sensors

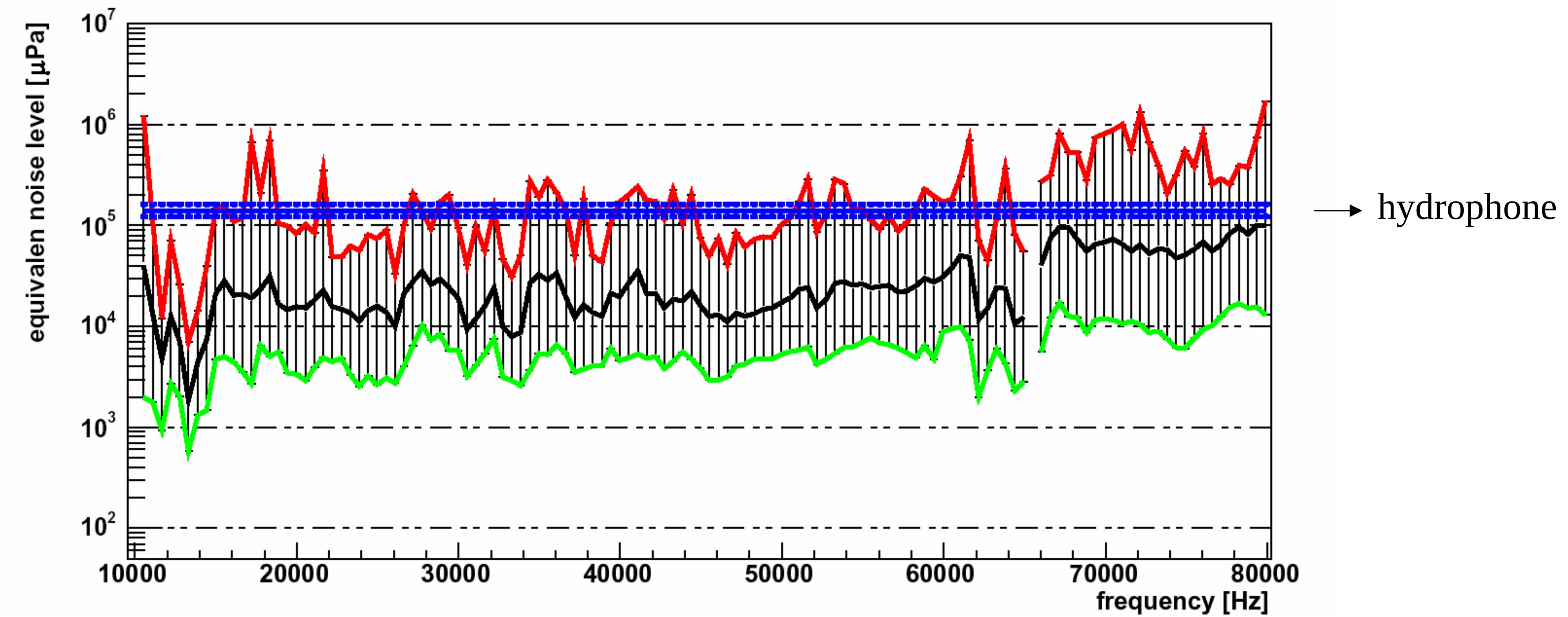
I) Absolute sensitivity range for all sensors [dB re V/mPa]



Effective detection threshold
⇒Not determined by sensitivity
⇒Most important is signal to noise

Results: overview for all sensors

II) Equivalent noise level [mPa] for each sensor module and all channels

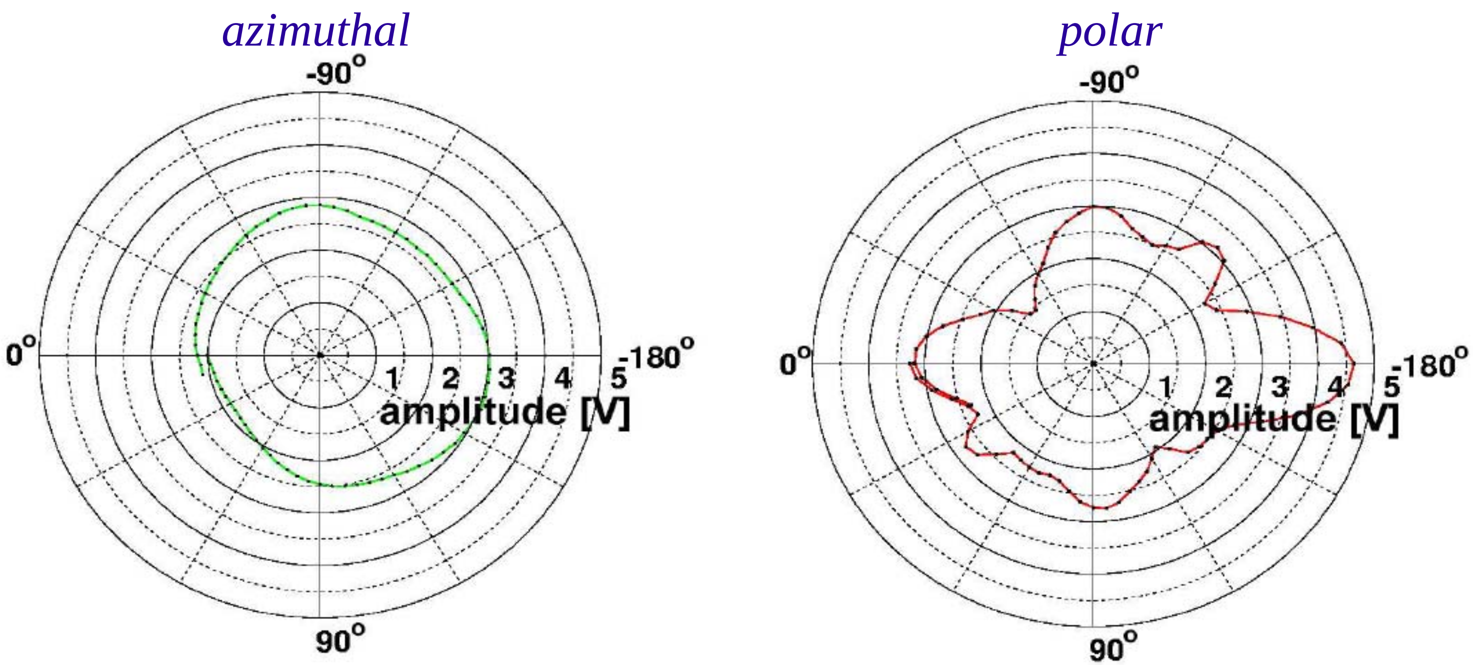


Equivalent self noise level
⇒Different for each sensor
⇒For most modules: 11mPa-83mPa
⇒Hydrophone: 150mPa

Transmitter tests

Transmitter properties:

=> amplitude uncertainties due to directivity



In final deployment: random orientation → systematical error

- no control of azimuthal orientation: **≈ 40%**
- possible tilting → polar orientation: **< 10%** for ± 10°

=> Directivity determines uncertainty in amplitude measurements

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Goals

Test the transmitters:

=> What are the variations between different transmitters

=> What is the range?

Test the SPATS sensors, use commercial hydrophone as reference:

=> Can we determine direction of pulse using the 3 channels per sensor?

=> Is the SPATS sensor performing better than the hydrophone?

Test the DAQ-software

=> What is the rate of readout failures?

=> Can we readout all channels?

Test the hardware

=> How robust is the system?

Frozen lake long range test

Setup

Location:

Abisko, North Sweden:

- 68°21'N,18°49'E
- 385m altitude
- Lake Torneträsk

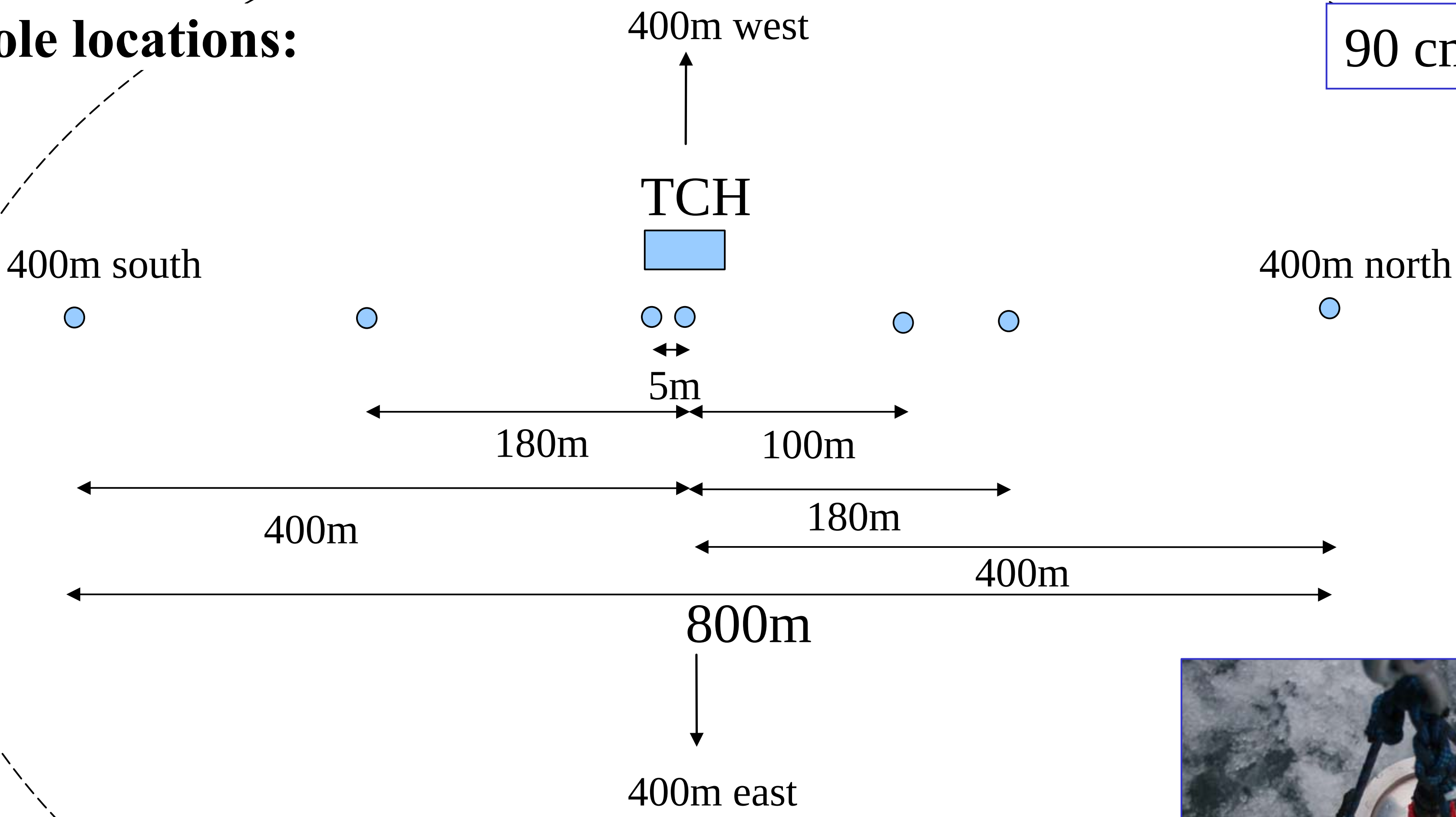
- **Large volume of water**
  => reflections are expected to be clearly seperated from the signal
- **Frozen surface**
  => easy deployment
  => relatively silent

→Deploy the transmitters, sensors and hydrophone:
→At different distances (max. distance =800m)
→At different depths (max. depth =64m)

Setup

Hole locations:

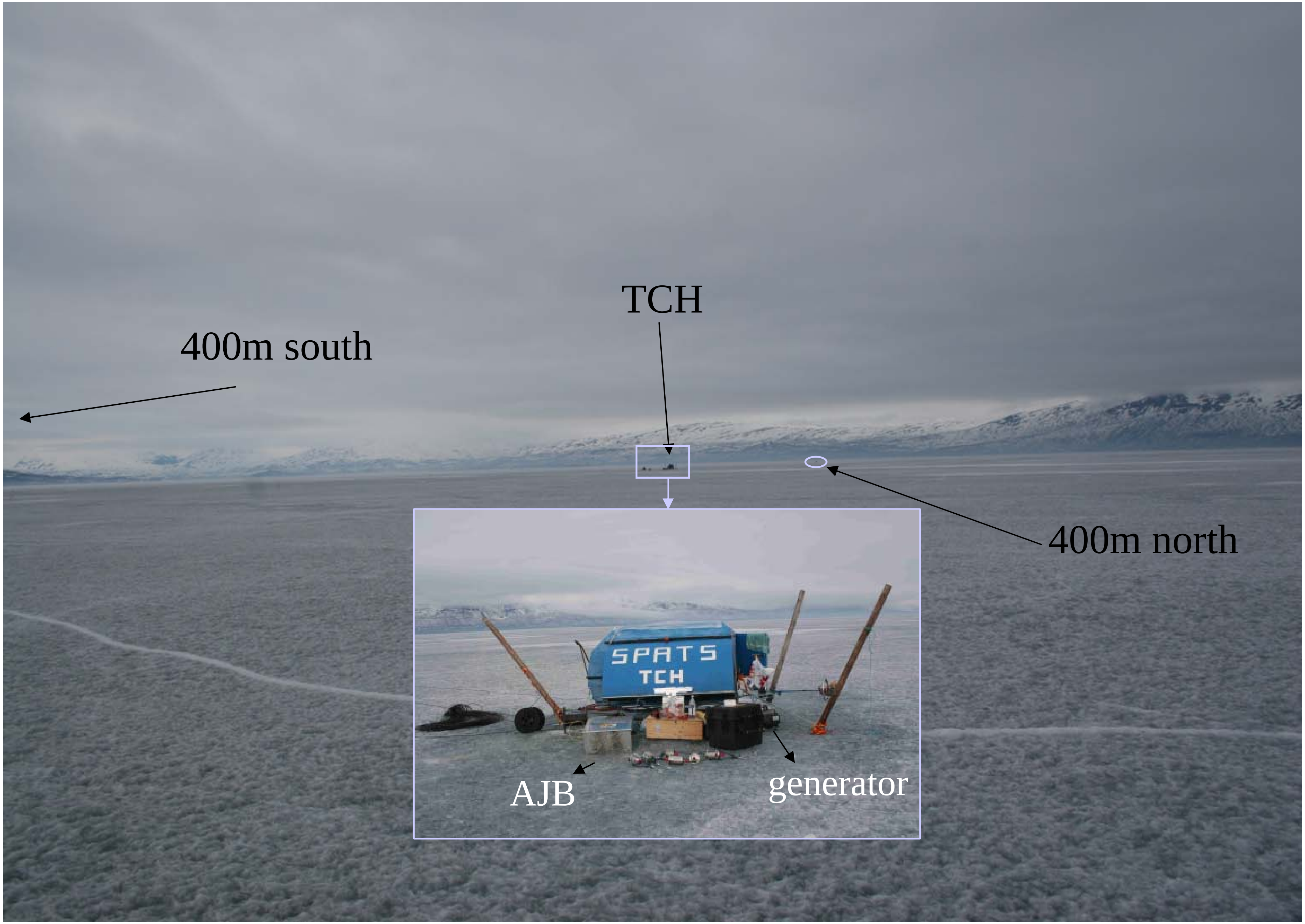
90 cm thick ice



→Deployment:
- →Lower a complete stage
- →In-ice cable + support cable

Frozen lake long range test

Setup



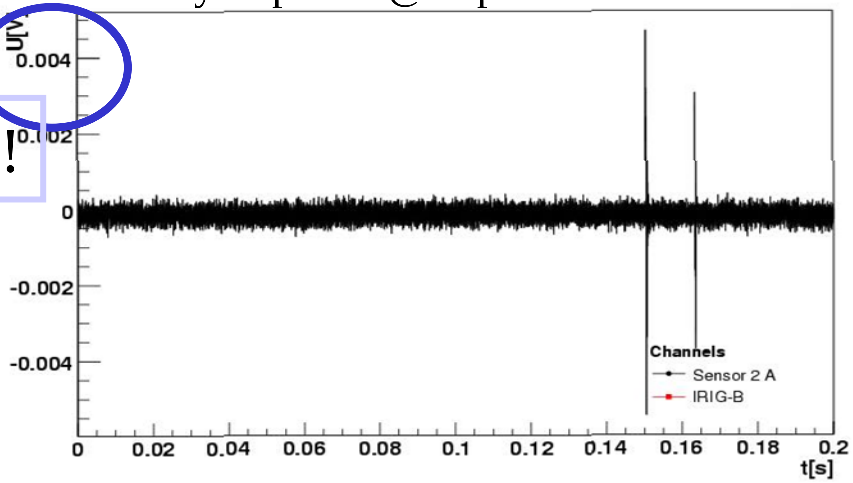
Results

Hydrophone vs. SPATS sensor:

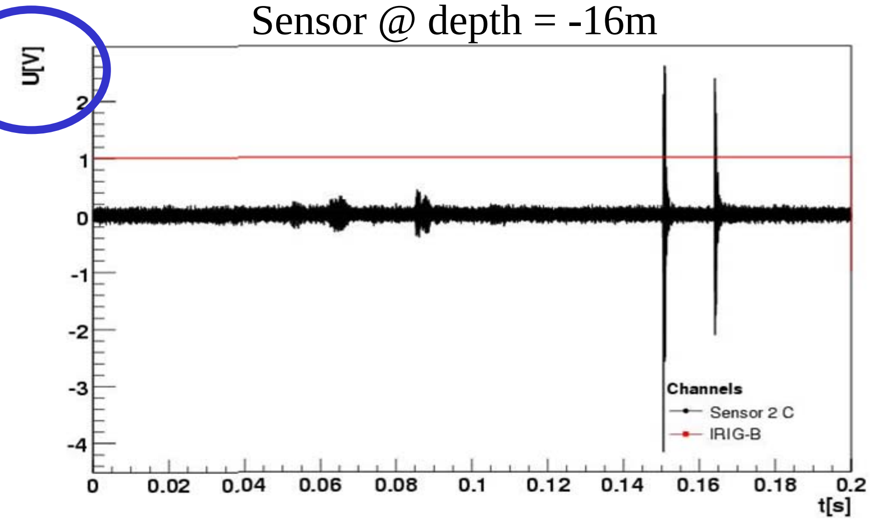
Transmitter @ 100m distance, depth =-30m

Hydrophone @ depth= -16m

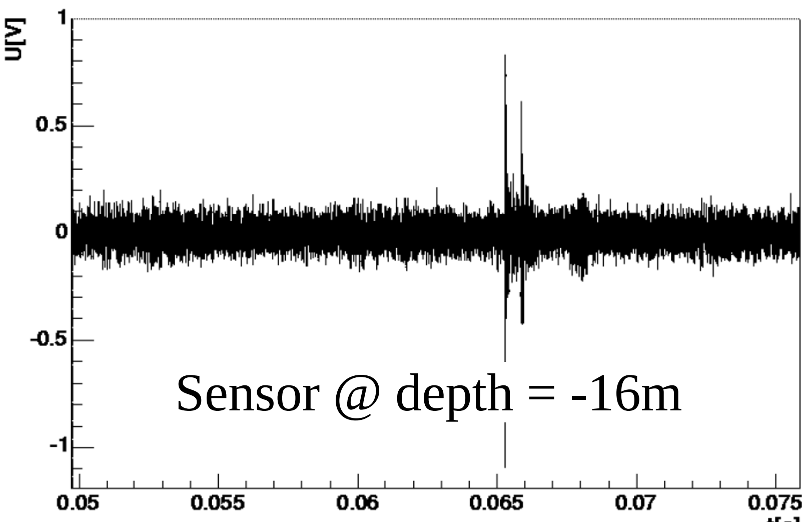
scale!

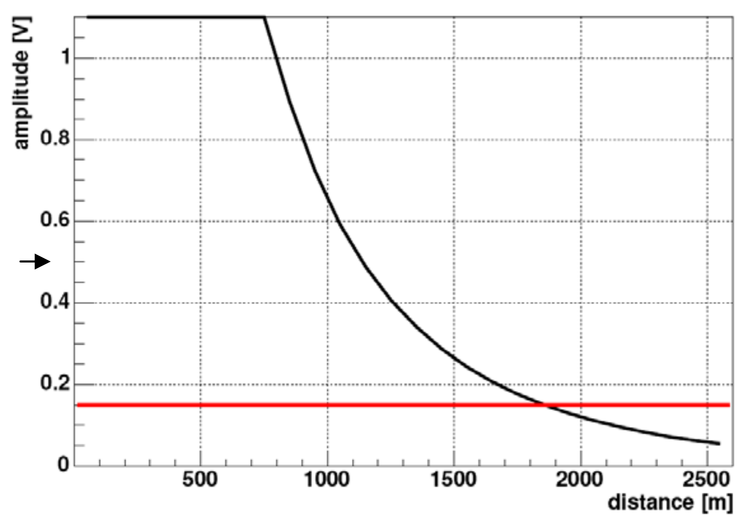


Sensor @ depth = -16m



Transmitter range:





Transmitter @ 800m distance, depth =-30m

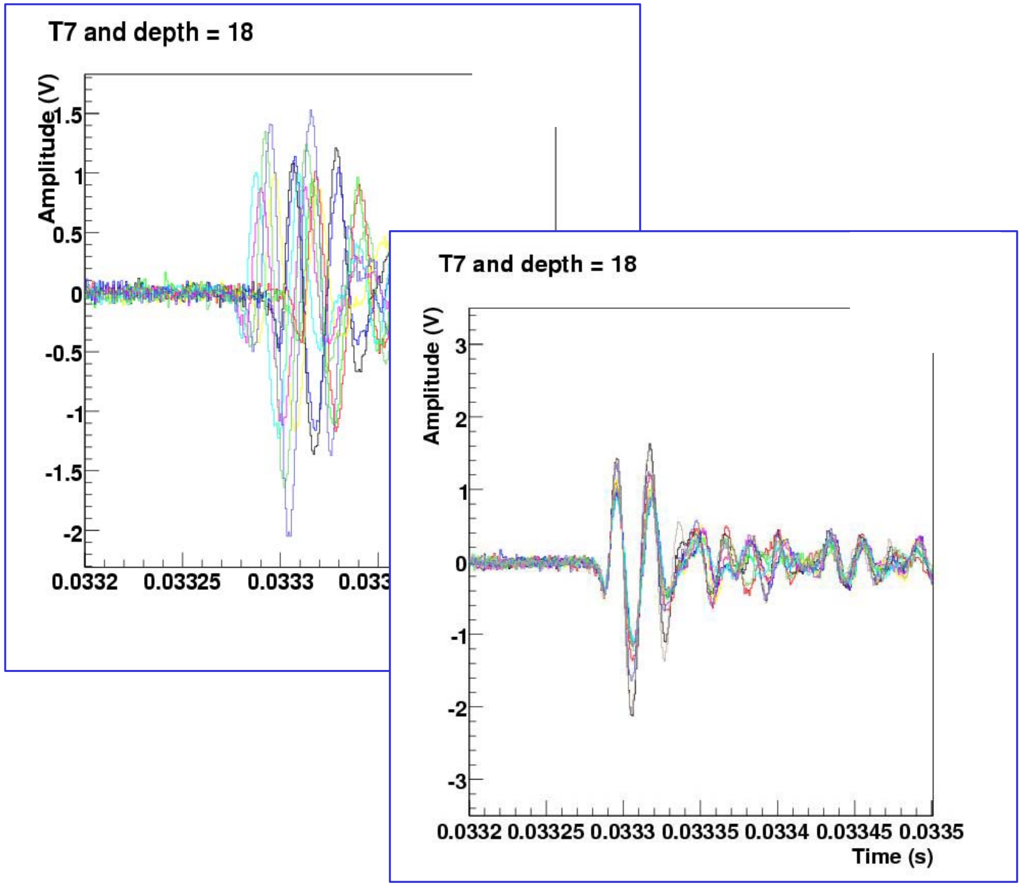
⇒Signal/Noise =1 @ 1800m!!

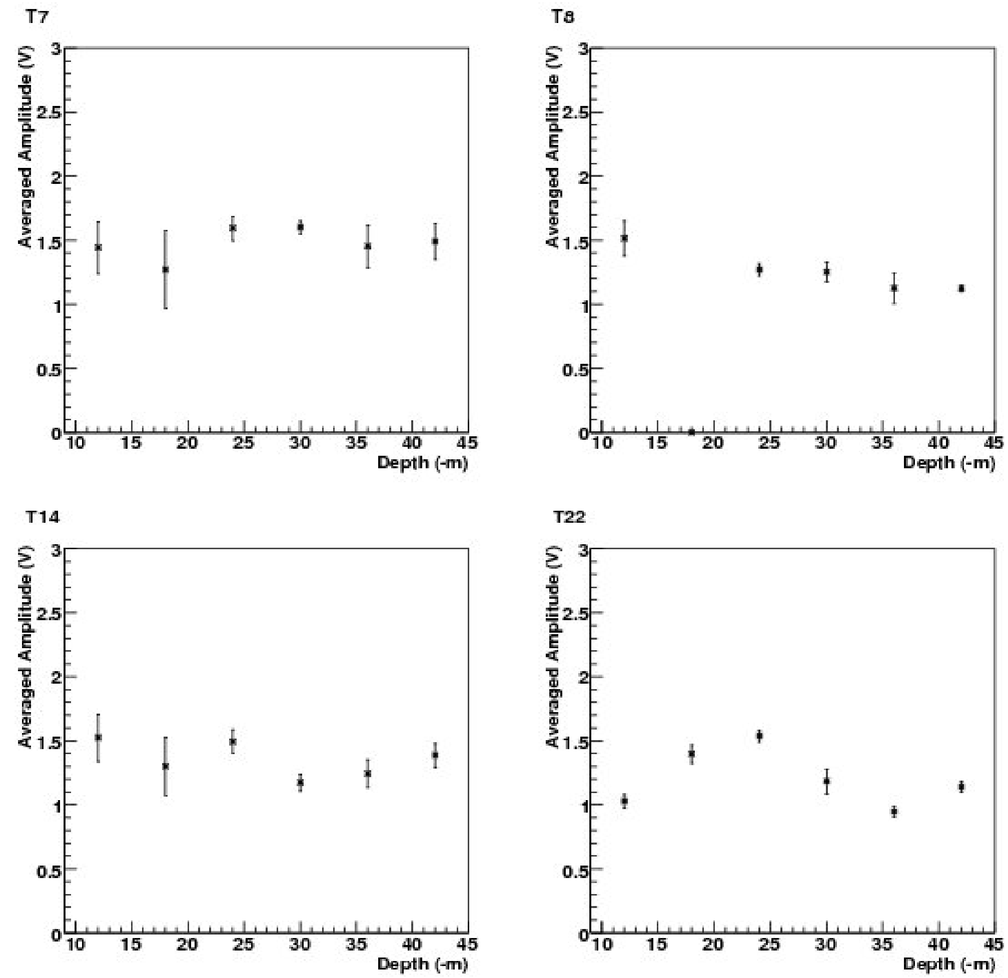
Frozen lake long range test

Results

Variations between transmitters:

SPATS sensor @ 400m distance, depth =-30m





⇒10 events @ each depth

⇒’swinging effect’

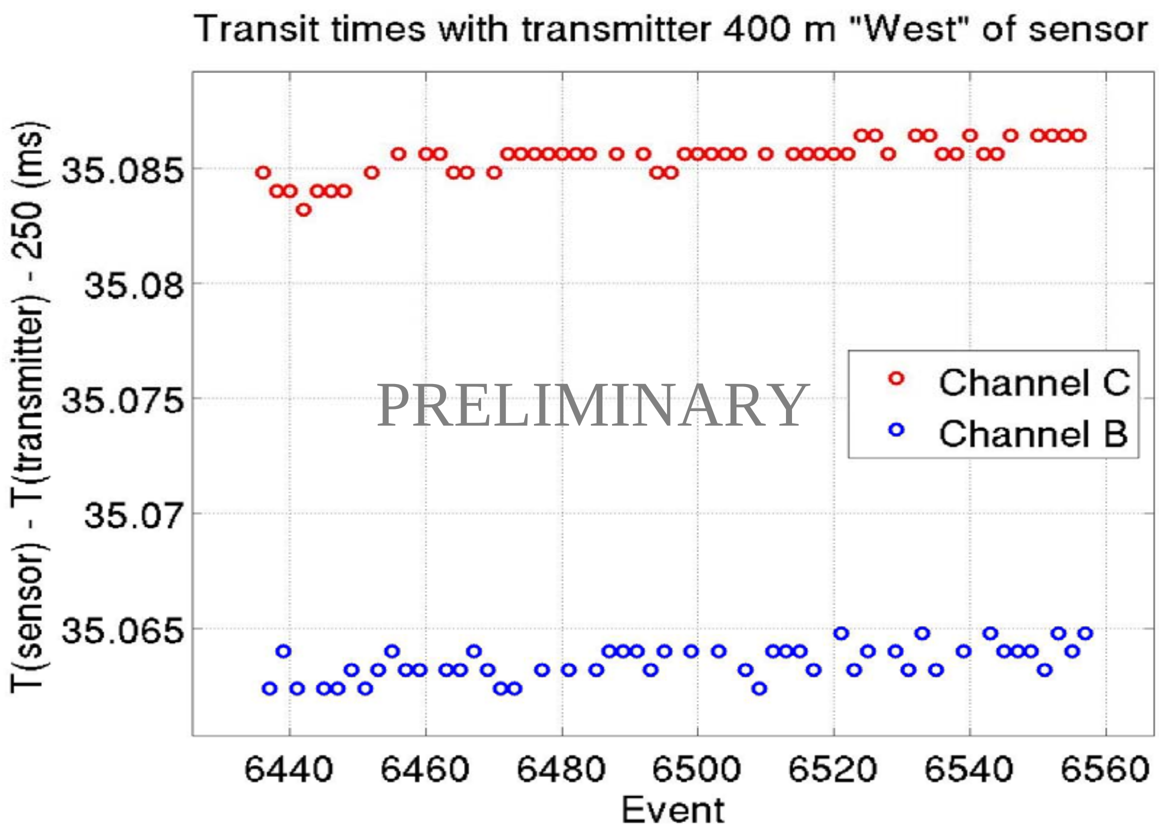
⇒take amplitudes of first peak

⇒All transmitters are clearly heard @400m.

⇒Variations are within expectations.

⇒Similar results for different ceramics

Sensor directional information:

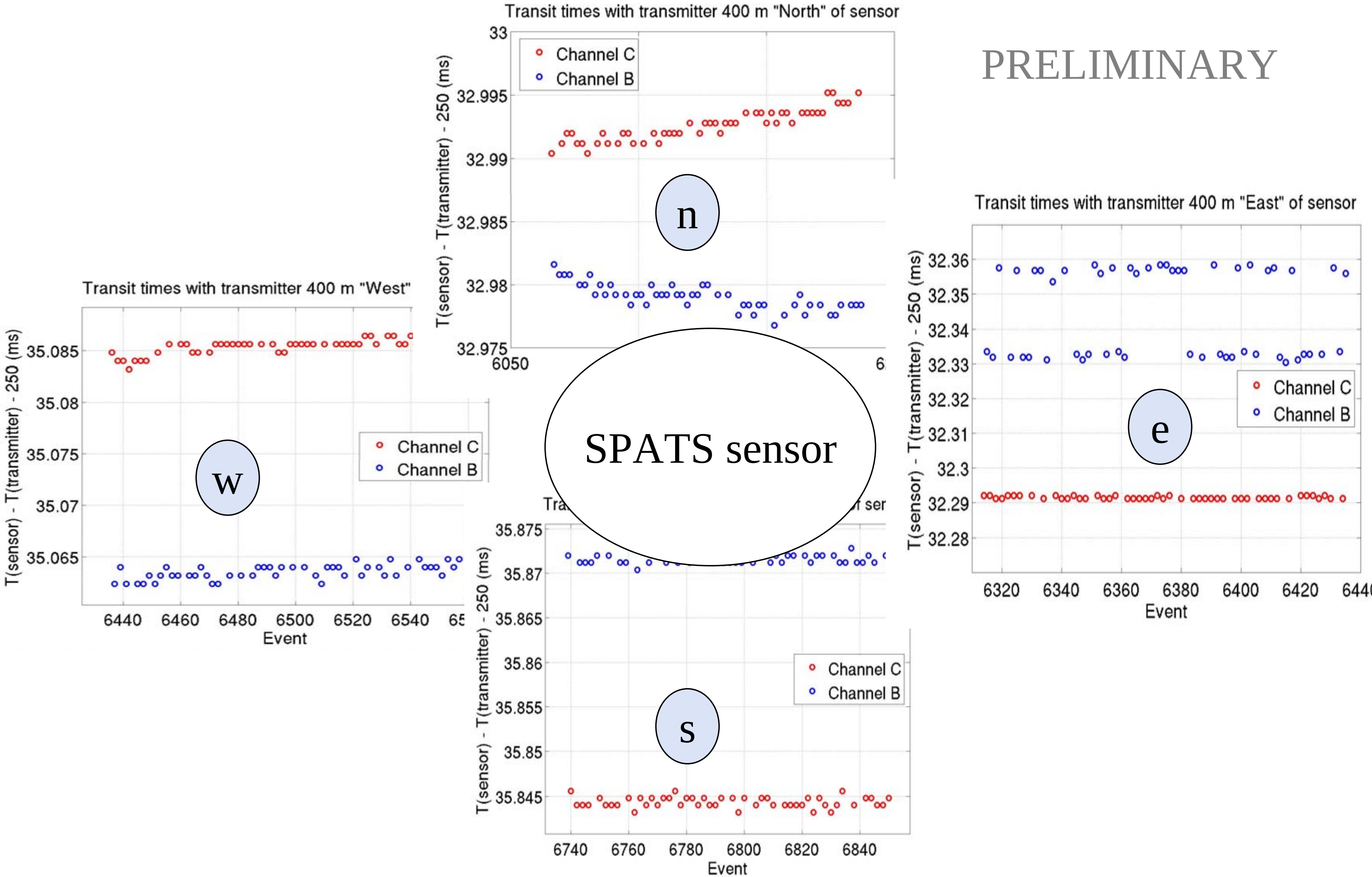


⇒3 channels are each separated by 10.47cm steel.

⇒Expected delays for signals are around 10 μs. (if v = 5790 m/s)

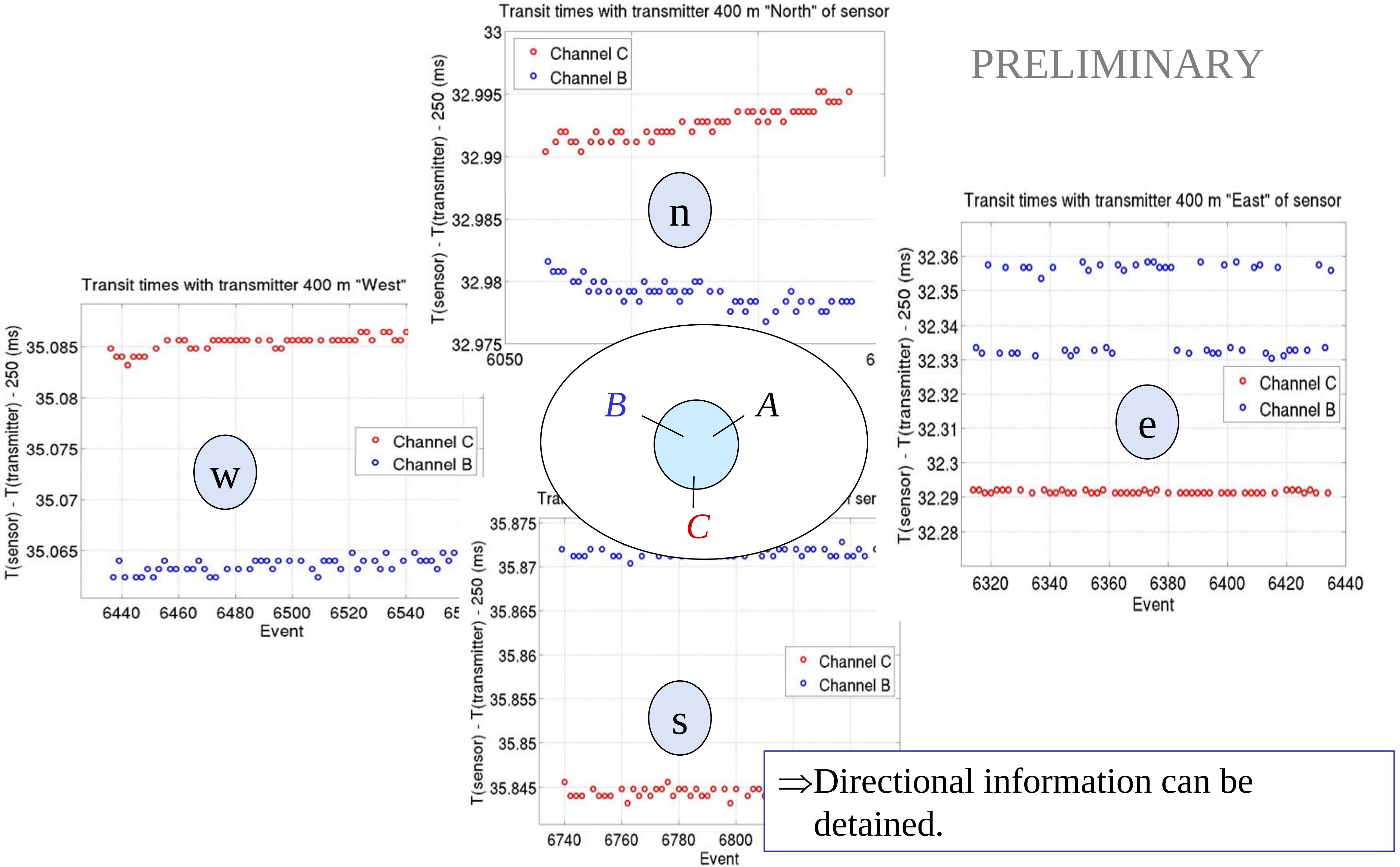
⇒Sampling rate = 1.25 MHz

Sensor directional information:



Sensor directional information:

PRELIMINARY



⇒Directional information can be detained.

=>SPATS calibration

-Sensors:

- 75 channels have been calibrated in water
- Range of mean equivalent self-noise level: 11mPa-83mPa

-Transmitters:

- Azimuthal and polar variation of pulse emission has been quantified
- HV-generator is stable
- Acoustic pulses are reproducible

=>Outdoor long range test:

→A complete system test has been accomplished.

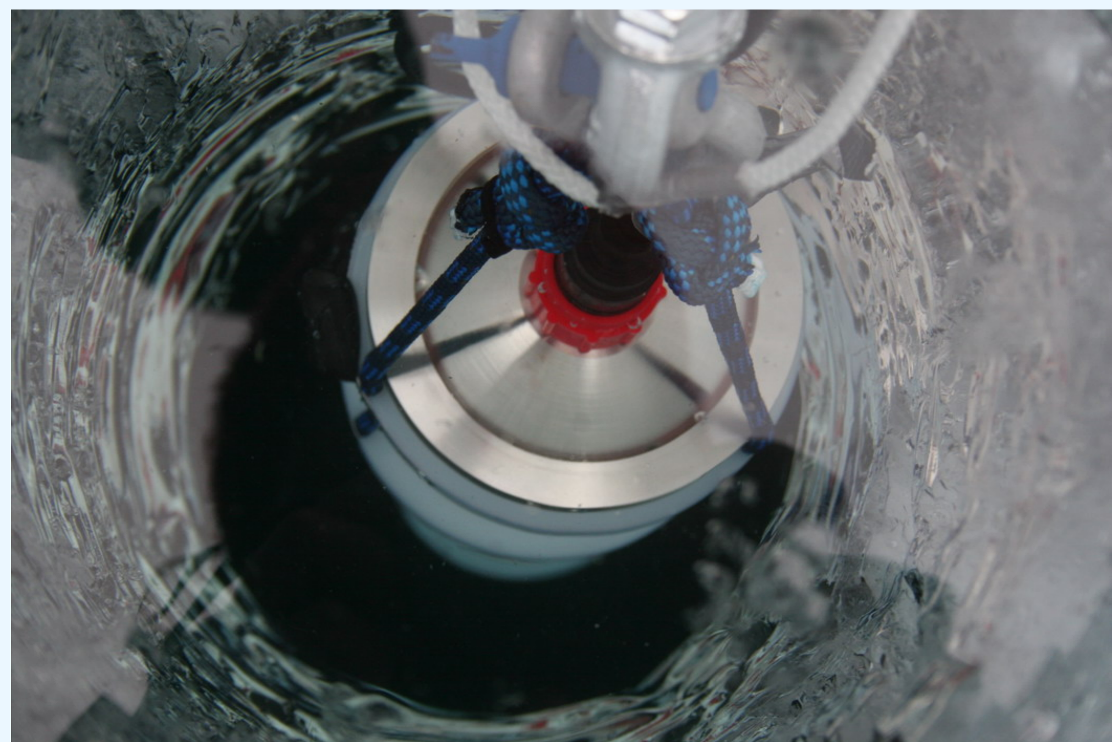
-SPATS sensors + transmitters meet the requirements.

-The system worked 'out of the box'.

→Calibration and verification has been performed

→The Abisko lake test was a success

→SPATS is a robust system!



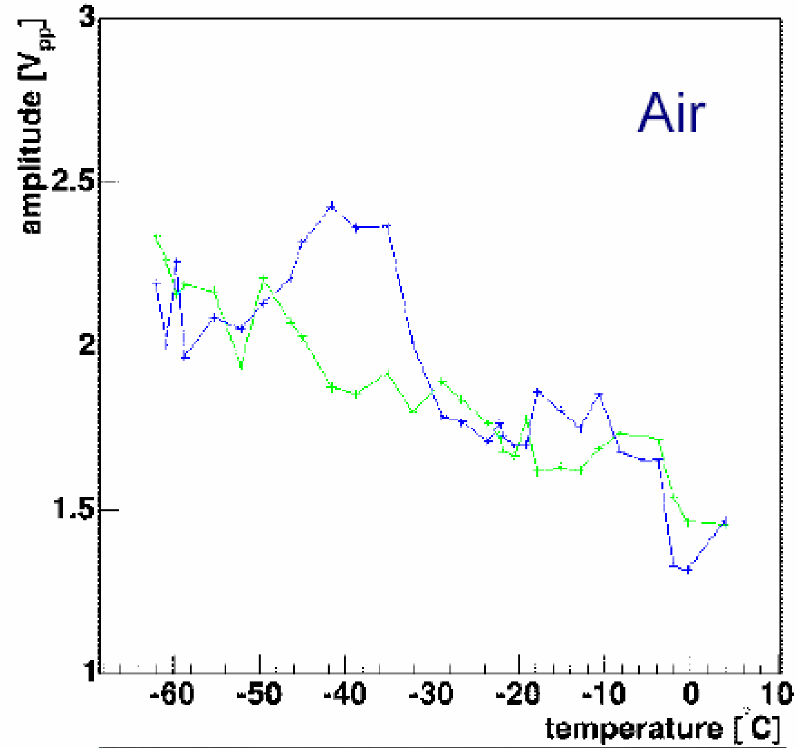
Backup Slides

Application to ice

Calibration only valid for water!

Ice vs. Water:

- different impedance matching
  - ➔ other resonance frequencies
- temperature: lower ➔ larger signals
- pressure: higher ➔ larger signals



In-Ice calibration problems:

- reflections ➔ large volume
- long freezing time
- fixed setups
- temperature control

➔ we are working on it!

directed transmitter