Status of the South Pole Acoustic Test Setup

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Outline

Motivation

- acoustic neutrino detection
- ice properties
- hybrid optical/radio/acoustic simulation

The SPATS project

- general setup
- in-ice devices
- data acquisition system
- communication

System testing

- summary
- Zeuthen Test Setup

Summary

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Motivation

UHE neutrinos:

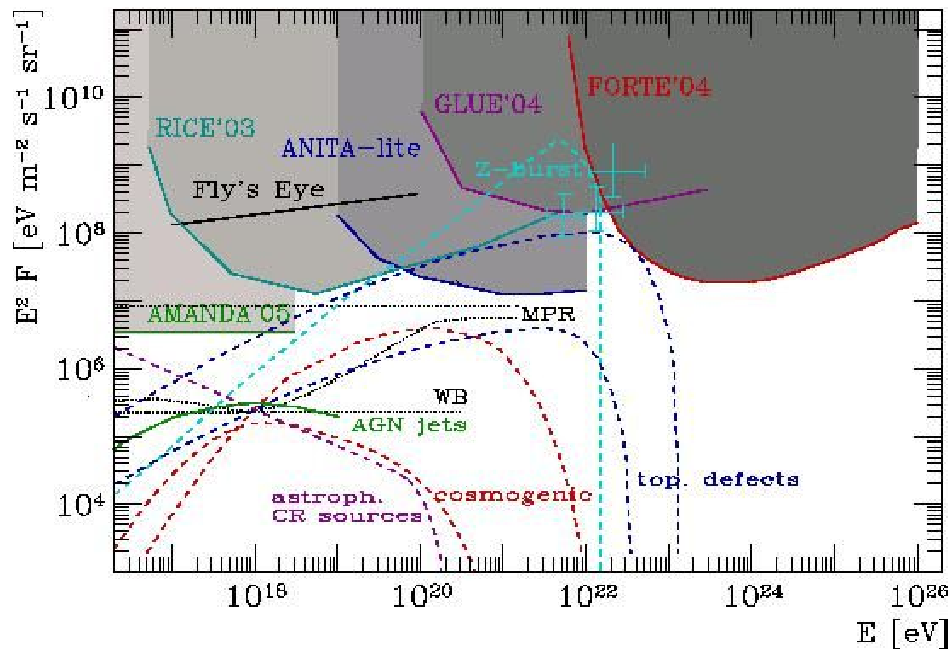
- many models (AGN, GZK, Z-Burst, TD,...)

➔ low fluxes

➔ large detector volumes ($> 10 km^3$)

➔ natural dense media (water, salt, ice)

➔ new detection methods (radio, acoustic)



In-ice detection methods:	optical	radio	acoustic
Absorption length [km]	~ 0.1	~ 1	~ 10
Directivity	$1/r^2$	1/r	1/r
Energy threshold [eV]	~ 10^9	~ 10^{15}	~ 10^{18}

Methods are complementary ➔ hybrid approach

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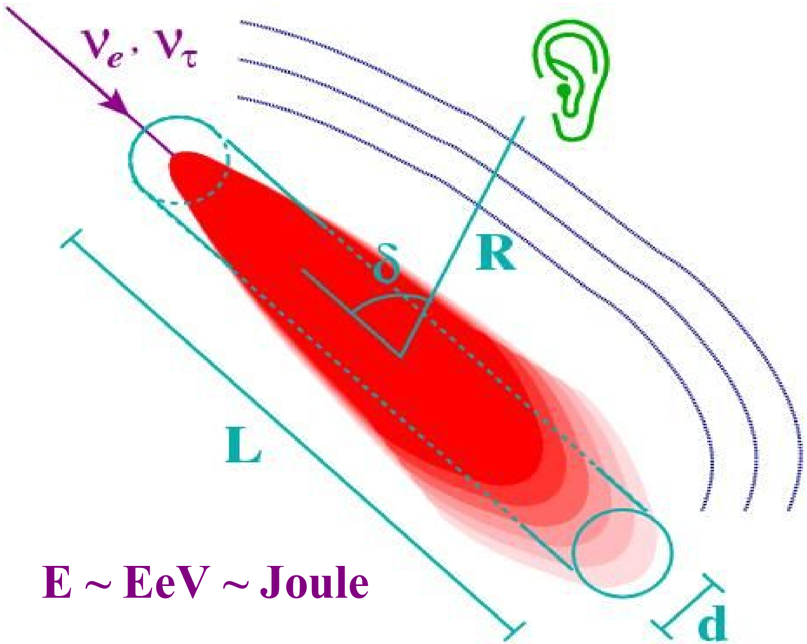
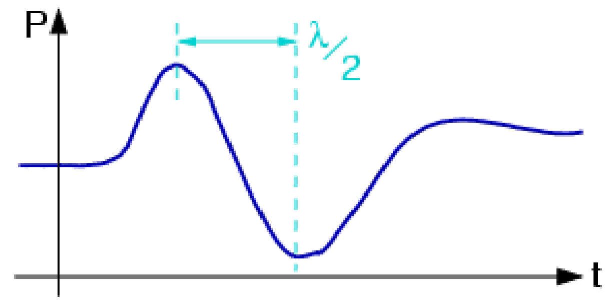
Acoustic detection



Acoustic signal:

$$P_{max} = \left(\frac{\alpha}{\mathbf{C}_p}\right)\left(\frac{\mathbf{f}^2}{2}\right) \cdot \frac{E}{R} \cdot \frac{\sin x}{x}$$

with $x = \frac{\pi \mathbf{L}}{2\mathbf{d}} \sin \delta$ and $f = \frac{\mathbf{v}_s}{2\mathbf{d}}$



Characteristic signal:

➔ good for background suppression

Peak pressure amplitude:

		Water (20 °C)	Ice (−50 °C)
$\mathbf{P}_{\mathbf{max}}$	$\left[\mathrm{Pa}\,\frac{\mathrm{E[PeV]}}{\mathrm{R[m]}}\right]$	$0.22 \cdot 10^{-3}$	$2.2 \cdot 10^{-3}$

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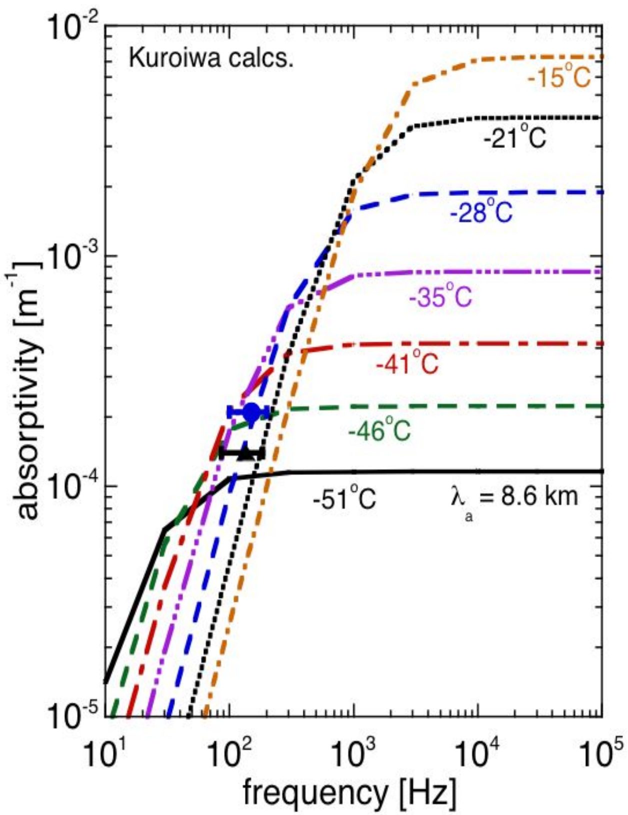
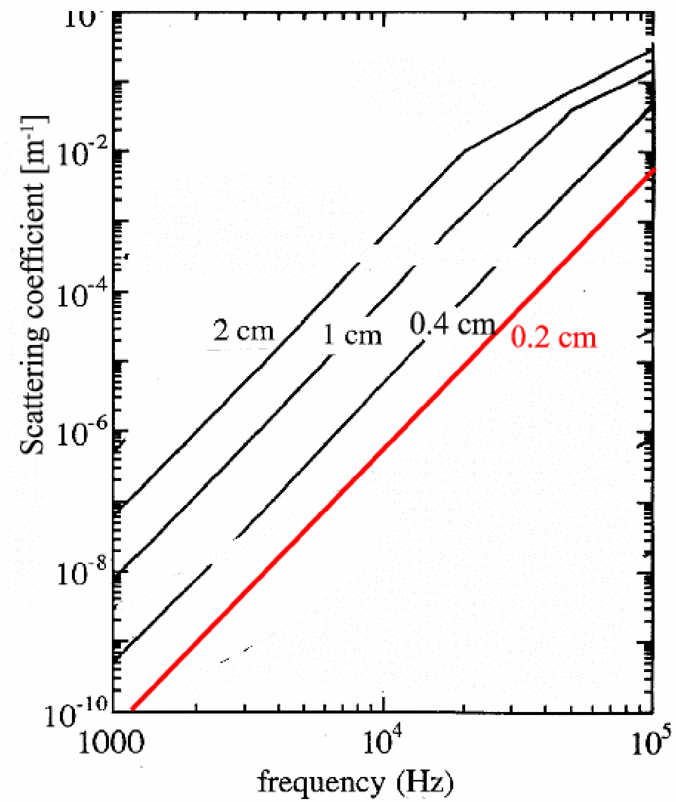
Ice properties

B. Price, UC Berkeley





Absorption:

- molecular reorientation

➔ energy loss in relaxation

➔ λ_{abs} (-51 °C) ≈ 8.6 km

Scattering:

- Rayleigh on crystal boundaries

➔ λ_s (10 kHz) ≈ 800 km

➔ λ_s (100 kHz) ≈ 0.2 km

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Hybrid optical/radio/acoustic simulation

D. Besson et al.

Common neutrino sample:

- 10^{16}-10^{20} eV from 2π in ~1000 km^3
- ν_e,ν_μ,ν_τ with $E_{had} / E_{lept} = 0.2$
- flux: Phys.Rev.D 64, 093010(2001)

Optical (ν_μ^{CC}):

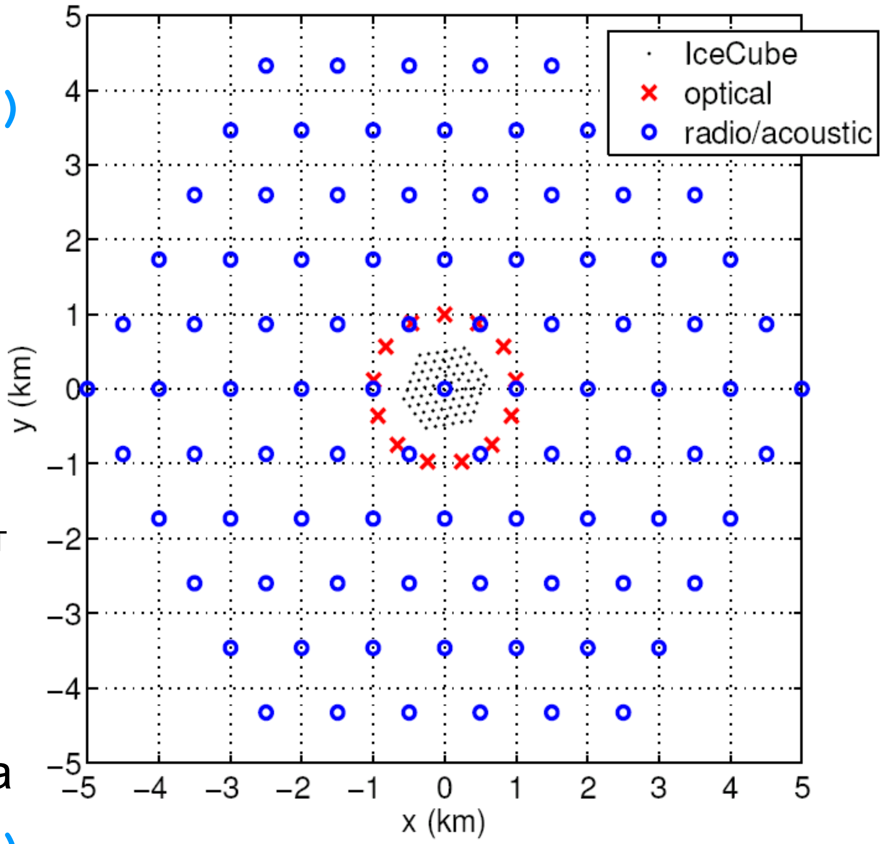
- IceCube + 13 strings ➔ 5580 modules
- full IceCube Monte Carlo

Radio ($\nu_{had}^{CC} + \nu_{had}^{NC}$):

- 5x2 modules / string with $A_{thresh} = 3.5\ \sigma_{kT}$
- signal: Phys.Rev.D 45, 362(1992)

Acoustic ($\nu_{had}^{CC} + \nu_{had}^{NC}$):

- 300 modules / string with A_{thresh} = 3 mPa
- sound: Phys.Rev.D 19, 3293(1979)
- analytic propagation



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Hybrid optical/radio/acoustic simulation II

Results:

- total:

  ~ 20 events / year

- radio/acoustic:

  > 10 events / year

- optical:

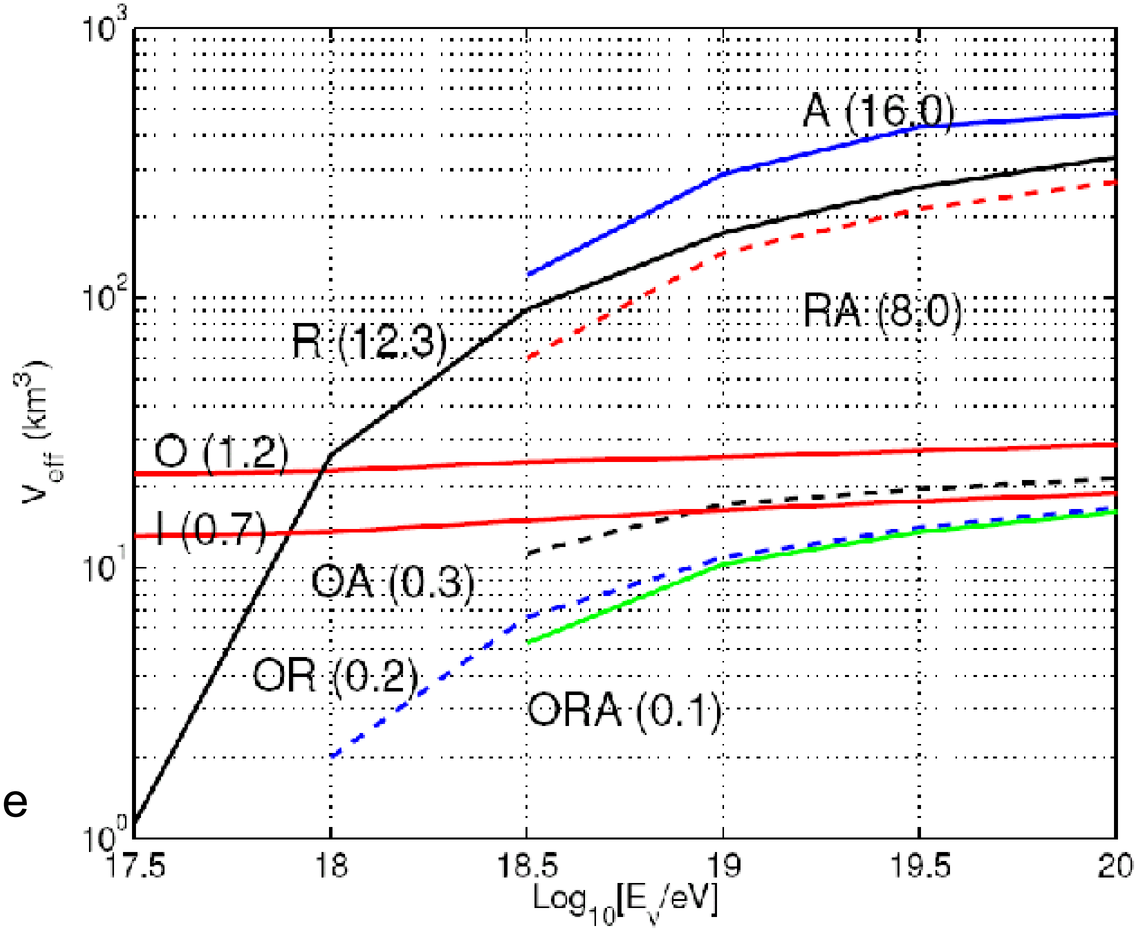
  ~ 1 event / year

Coincident events:

- radio/acoustic:

  ~ 8 events/year

➔ cross calibration possible



Published in Proc. of 29th ICRC (Pune, 2005), astro-ph/0512604

Simulation uncertainties

	theoretically	experimentally
Event rates:		
• neutrino flux	models	☺ - ☺ - ☺
• cross section	extrapolation	angular spectum
Signal generation:		
• shower development	no exp. + CPU power	signal shape
• acoustic pulse	energy deposit	verified at protonbeam
Signal propagation:		
• speed of sound	other frequencies	missing
• absorption	extrapolation	missing
• scattering	extrapolation	missing
Detector simulation:		
• self noise	model	measured
• ambient noise	unknown	missing

Need a dedicated setup to measure ice parameters !!!

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Absorption measurement 06/07

Holes:

- drilling expensive ➔ bound to IceCube holes

Absorption measurement: $A(S_i,T_j) = S_i\ T_j\ 1/d_{ij}\ e^{-\alpha d_{ij}}$

- small effect ➔ maximize distance
- **no in-ice calibration**

➔ use redundant information e.g.

- all three sensor - transmitter combinations

$$A(S_i,T_j)/A(S_i,T_k) = T_j/T_k\ d_{jk}/d_{ij}\ e^{-\alpha(d_{ij}-d_{ik})}$$

- transmitter output ratio from water meas.

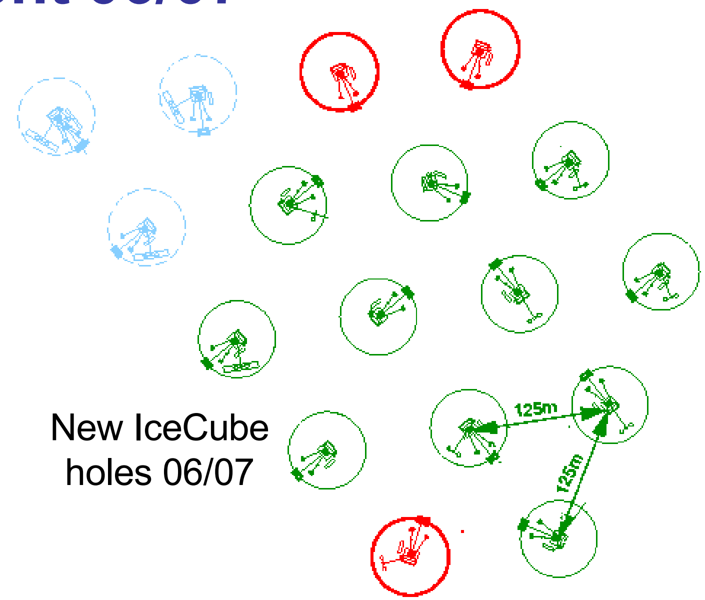
$R = T_i/T_j \pm \Delta R_{syst}$ ➔ 6+3 equations for 7 parameters

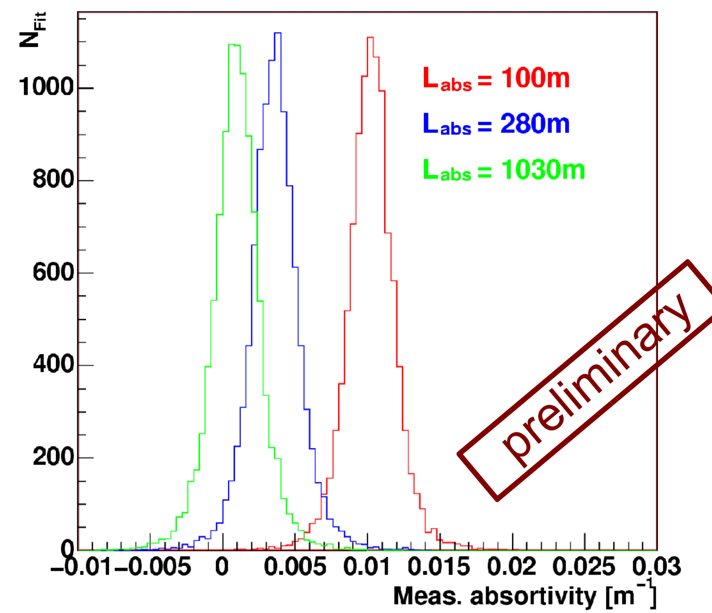
- ΔR_{syst} mostly azimuthal orientation (talk F. Descamps) ➔ random

➔ with a 50% chance for $<\Delta R_{syst}> = 10\%$

L_{abs} > 1200m or better (3σ C.L.)

➔ need more sensors and transmitters





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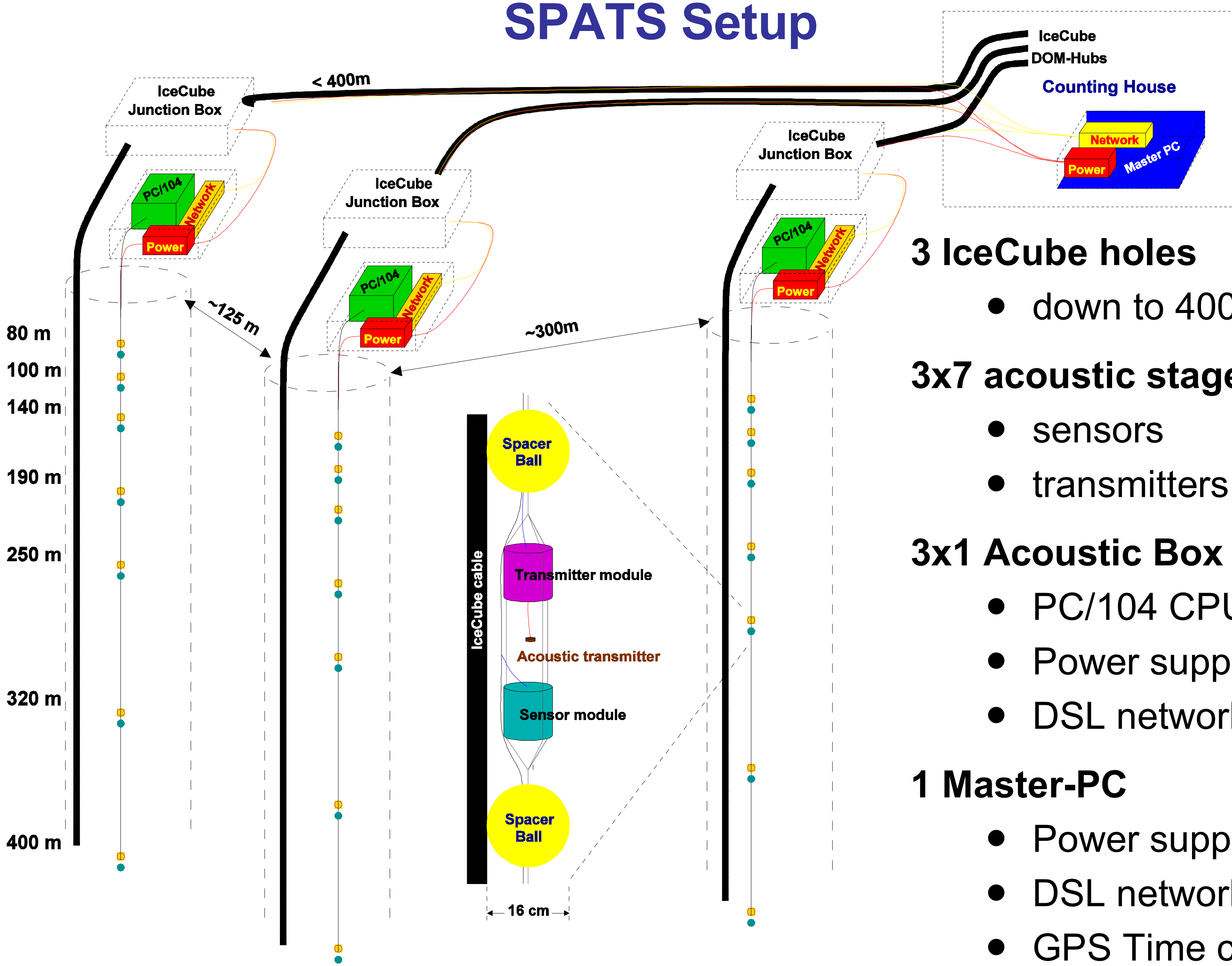
SPATS Setup



3 IceCube holes
- down to 400m

3x7 acoustic stages
- sensors
- transmitters

3x1 Acoustic Box
- PC/104 CPU
- Power supply
- DSL network

1 Master-PC
- Power supply
- DSL network
- GPS Time code

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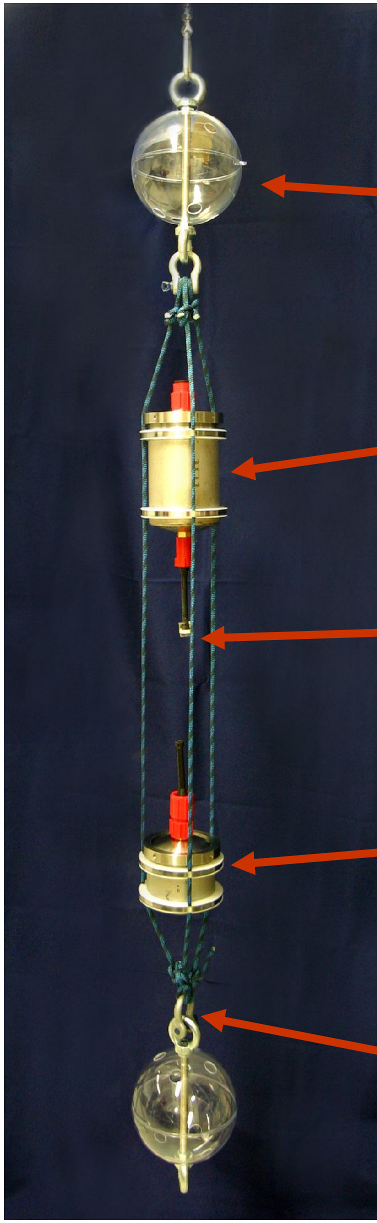
Participants



Acoustic stages

Spacer balls
- ensure distance to walls and IC cable
- large holes to flood with water

Transmitter module
- HV pulse generation (1kV @ 10μs)
- temperature / pressure sensors

Transmitter
- ring-shaped piezoceramics
  - ➔ generates acoustic wave

Sensor module
- three channels
  - ➔ directional sensitivity
  - ➔ noise rejection

Solid junctions
- shackles, ropes, etc. specified for ≥ 22kN

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Sensor module

Piezo ceramics

- individually calibrated

Three-stage amplifier board

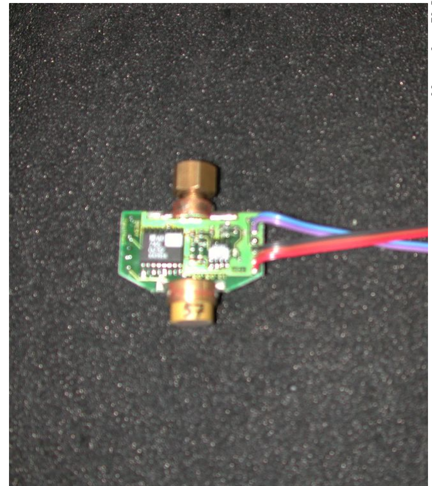
- low noise
- differential output

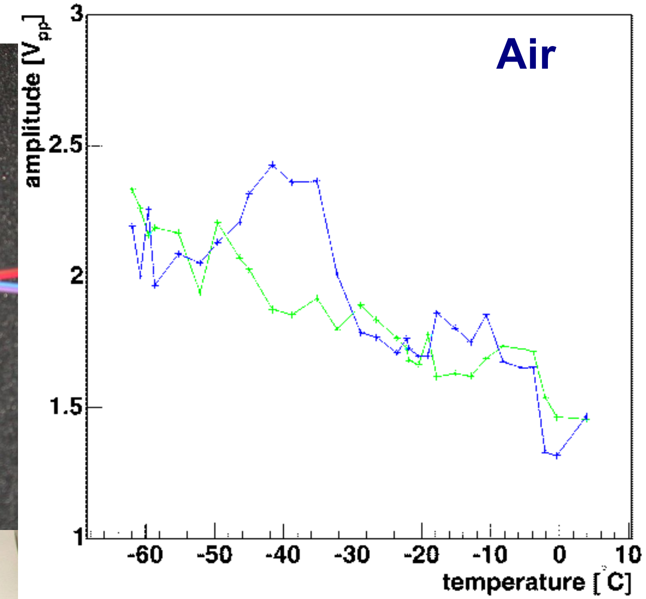
Mechanical contact

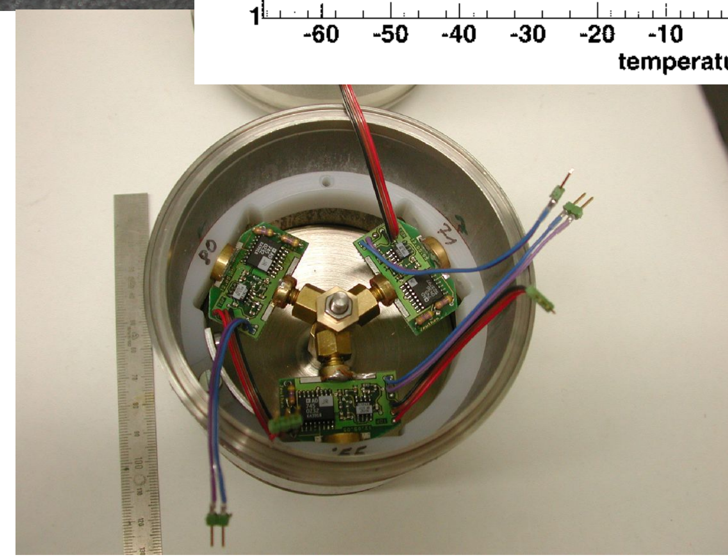
- Preload screw
  ➔ signals get larger
  - at low temperature
  - at higher pressure

Sensor module

- three channels
- voltage conversion board
  36-13VDC ➔ ±5VDC







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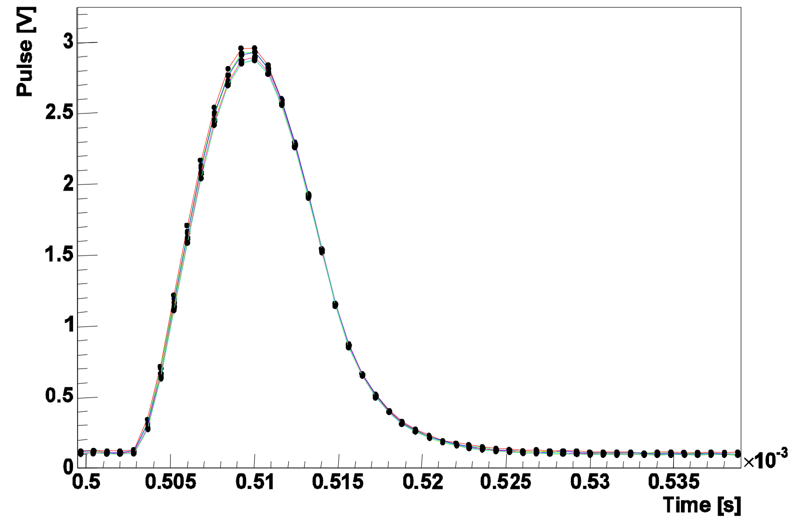
Transmitters



HV pulse generation

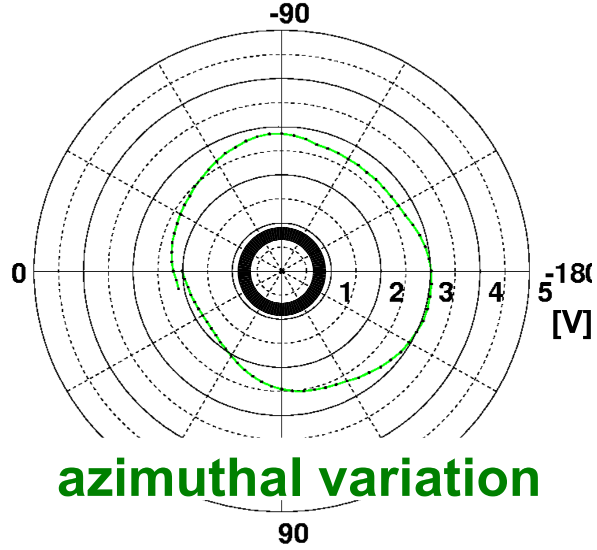
- discharge LC circuit via piezoceramics
  - ➔ ~1kV pulse of ~10µs
- remote amplitude control
- remotely triggered by TTL pulse
- signal read back scaled 1:100

Transmitter

- external ring ceramics
  - ➔ uniform emission

Auxiliary sensors

- 3 pressure sensors in lowest modules
- temperature sensors



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In-ice cable

Requirements

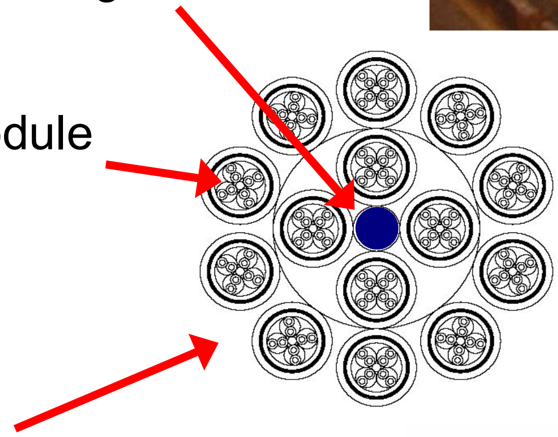
- ~ 200 kg load
- low loss @ 100kHz (analog signals)

Central support rope

- takes weight of string
- knots to connect acoustic stages

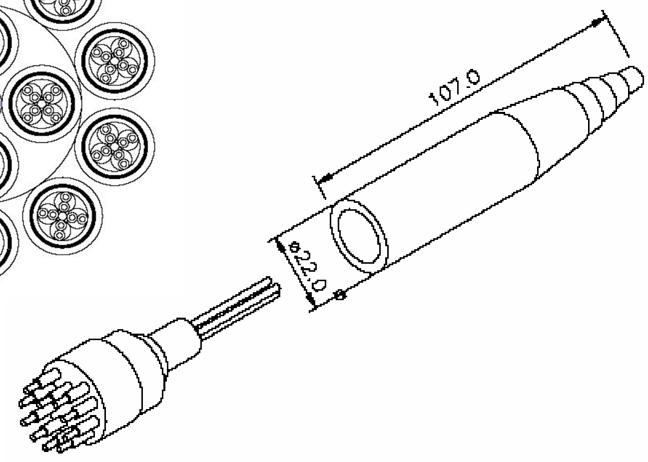
Electrical cables

- four twisted pairs per module
- common shield



Cablage

- two helical layers
- nom. diameter: 31.5 mm



Connectors

- 10-pin SubConn underwater mateable

In-Ice cables and connectors are 50% of total cost !

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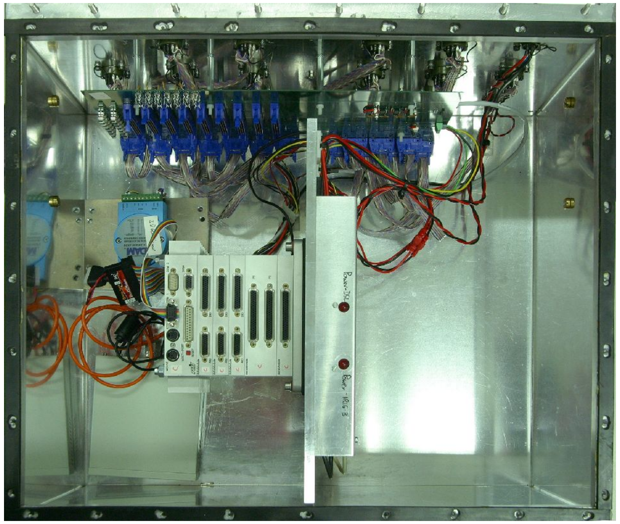
String-PC



String electronis:

- in snow ➔ -10 ºC to -60 ºC
- long cables ➔ limited power

Acoustic box:

- DC-DC converter: 96V ➔ 5V, 12V, 24V
- Communication: DSL Modem & RS422 serial
- Filter, fuses, cable drivers, etc..

PC/104 system:

- CPU module: 600MHz, 512 MB RAM
- 3 fast ADC boards: 1.25 MHz @ 12 bit
- 1 slow ADC board: temperature, pressure
- 1 relais board: power control

➔ all components: +80ºC to -40ºC

➔ power consumption: 35W norm. , 55W max.

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Master-PC

System control:

- interface to string electronics
- part of south pole network

Power supply:

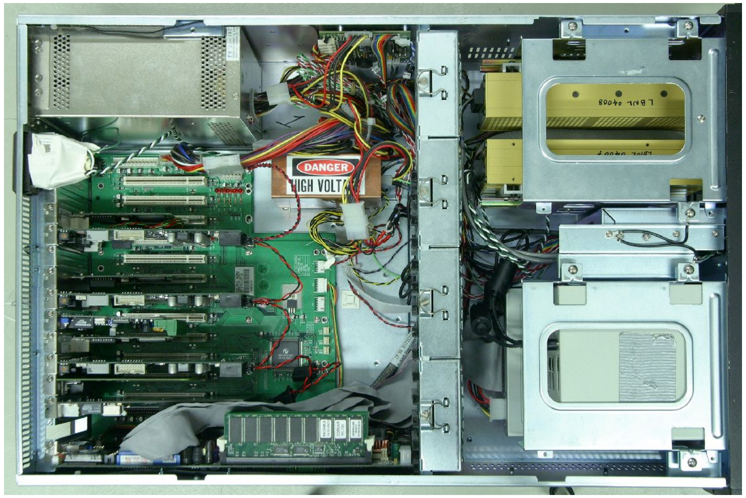
- 96V @ 150 W (standard IceCube)
- independent of PC

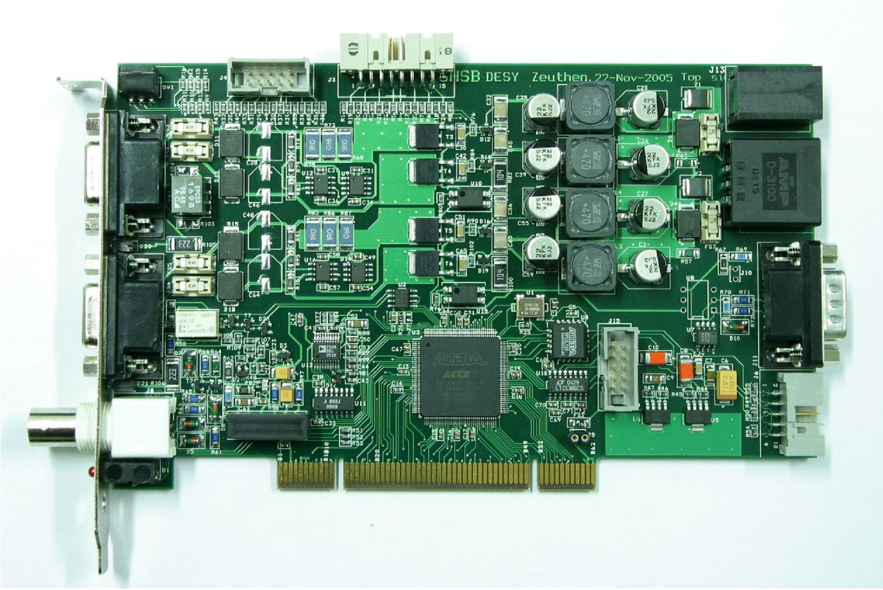
SPATS Hub Service Board

- Power and connection control
- Current and voltage limits
  - ➔ FPGA controlled
- Signal routing

Communication:

- DSL Modems & RS422 serial
- GPS antenna
  - ➔ IRIG-B time synchronisation





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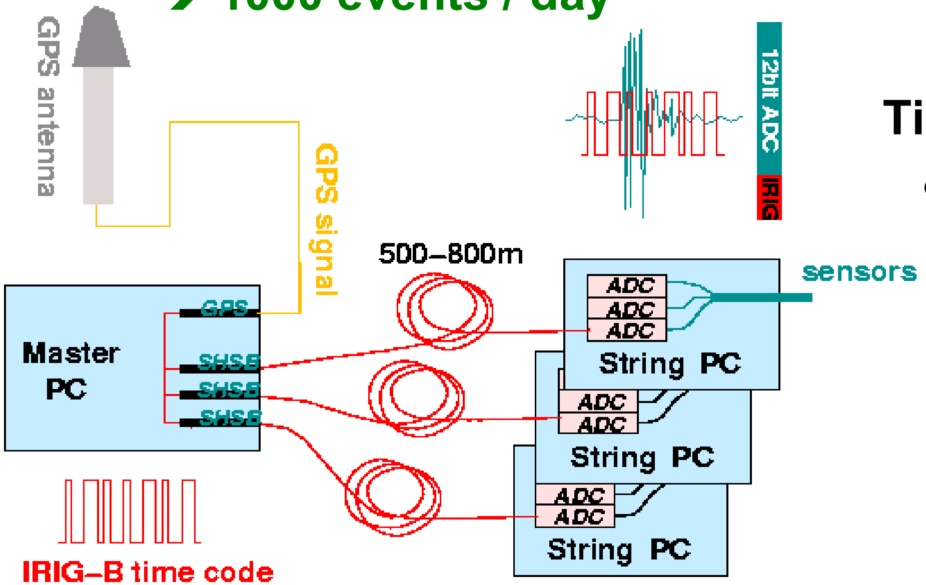
Communication and time synchronisation

System control and data taking only from northern hemisphere !

Data rates:

- max. 152 Mbps (57.2 Mbps/string)
  - ➔ software trigger at string
- DSL Modem: 2.3 Mbps ➔ to -20ºC
- RS422 serial: 38.4 kbps ➔ to -40ºC
- Satellite: ~56kbps (all experiments)
  - ➔ 1% ≈ 50MB / day for SPATS
  - ➔ **1000 events / day**



Time synchronisation:

- GPS receiver
  - IRIG-B time code (TTL binary)
    - cable driver on SHSB
      - receiver in acoustic box
      - ➔ **≈ 40µs jitter ≡ 15cm in ice**
        - sampled together with ADC
        - ➔ **0.8µs resolution**

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Testing summary

Modules:

- functionality and freezer test
- water calibration
  ➔ talk F. Descamps

String-PC:

- Comm. and DAQ tests
- Freezer tests

Communication:

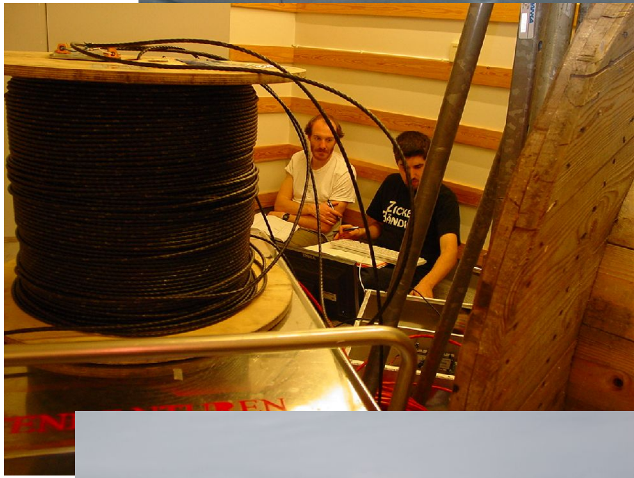
- original long cables
- in freezer

Outdoor:

- Zeuthen lake and Abisko
  ➔ talk F. Descamps

Full system:

- tested for 4 weeks in Zeuthen
  ➔ now: Zeuthen Test Setup



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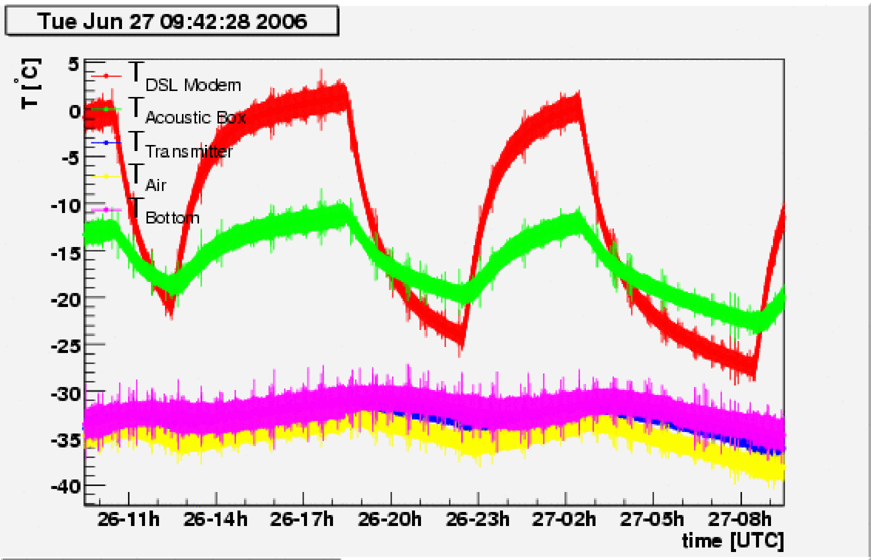
Zeuthen Test Setup

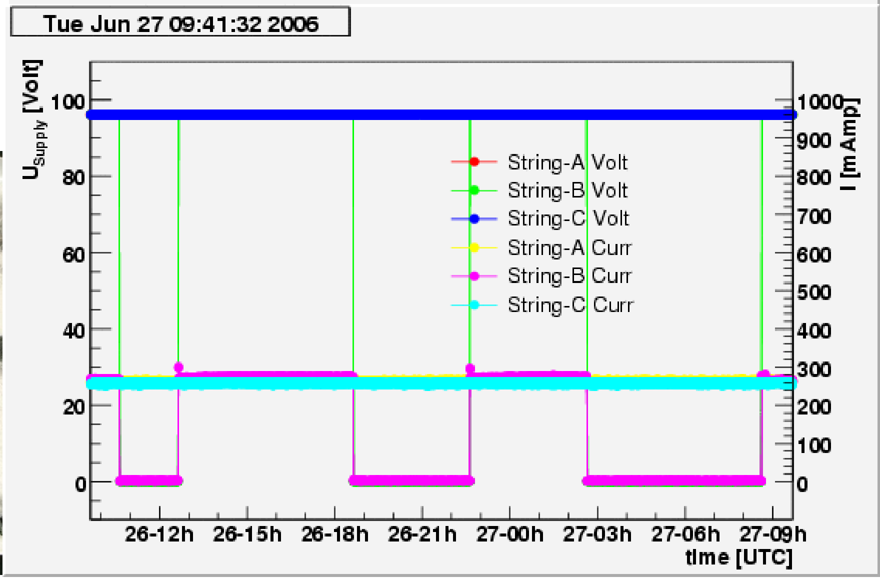
Aim:

- intensive long-term testing until deployment
- software development platform

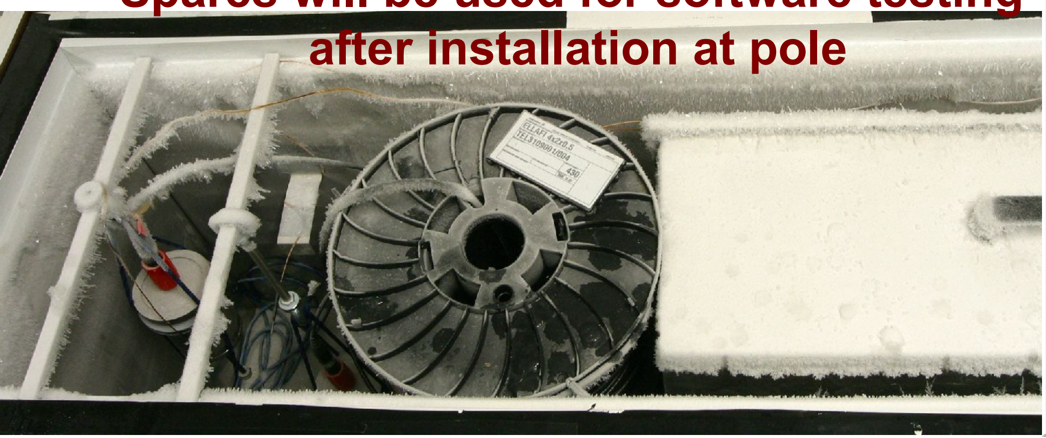
Current setup:

- original Master-PC
- original surface cables and simulators
- original acoustic boxes
- original and short in-ice cables
- original modules





Spares will be used for software testing after installation at pole



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Summary

Hybrid detector:

- ✓ promising event rates possible
- ✓ cross-calibration of radio and acoustic methods
- ✘ need ice parameters for more precise results

SPATS:

- remotely controllable many channel setup
  - ➔ overcome systematic errors
  - ➔ redundancy and background characterisation
- ✓ fully developed
- ✓ extensively tested

System is ready for deployment in next polar season !

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