IceCube,
Ultra High Energy Neutrino

Status report on acoustic neutrino detection

CHIPP Neutrino workshop, Nov. 2008

The IceCube "Observatory"

Very large scale hybrid observatory

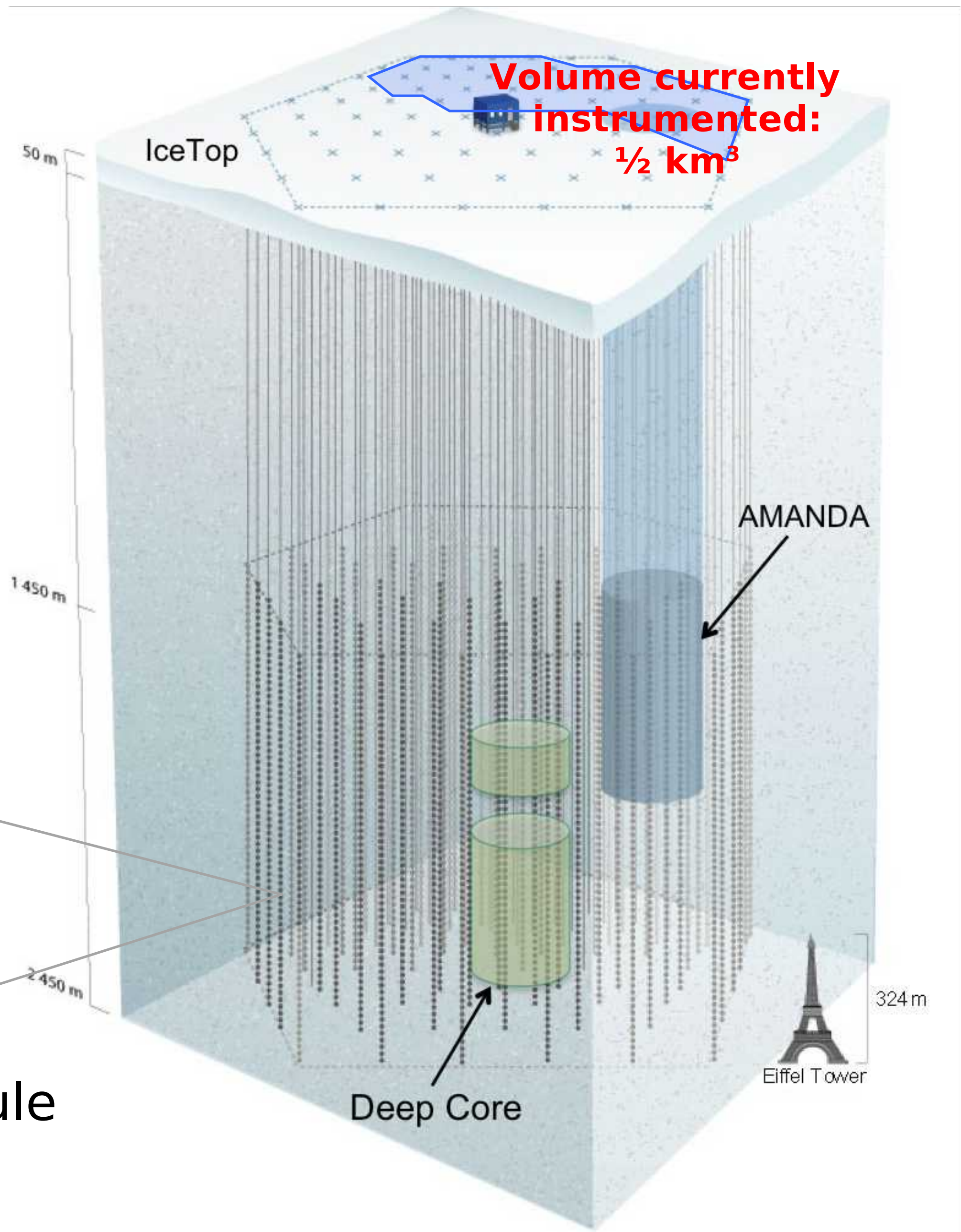
- 1km approximate diameter

IceTop

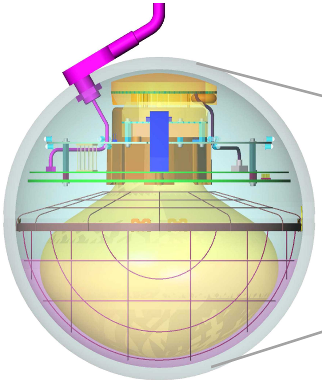
- Surface Air-Shower detector array
- Approximate threshold: 300 TeV

IceCube:

- 80 strings with 60 Digital OM's per string
- 125m interstring spacing, 17m DOM spacing



- 5th drilling season starting.
- IC40 taking data
- Plan to deploy 16 IceCube strings



Digital Optical Module (DOM)

IceCube Deep Core

- Decommissioning of AMANDA replaced by 13 string "Deep Core":

- Additional 6 strings embedded in the center of IceCube

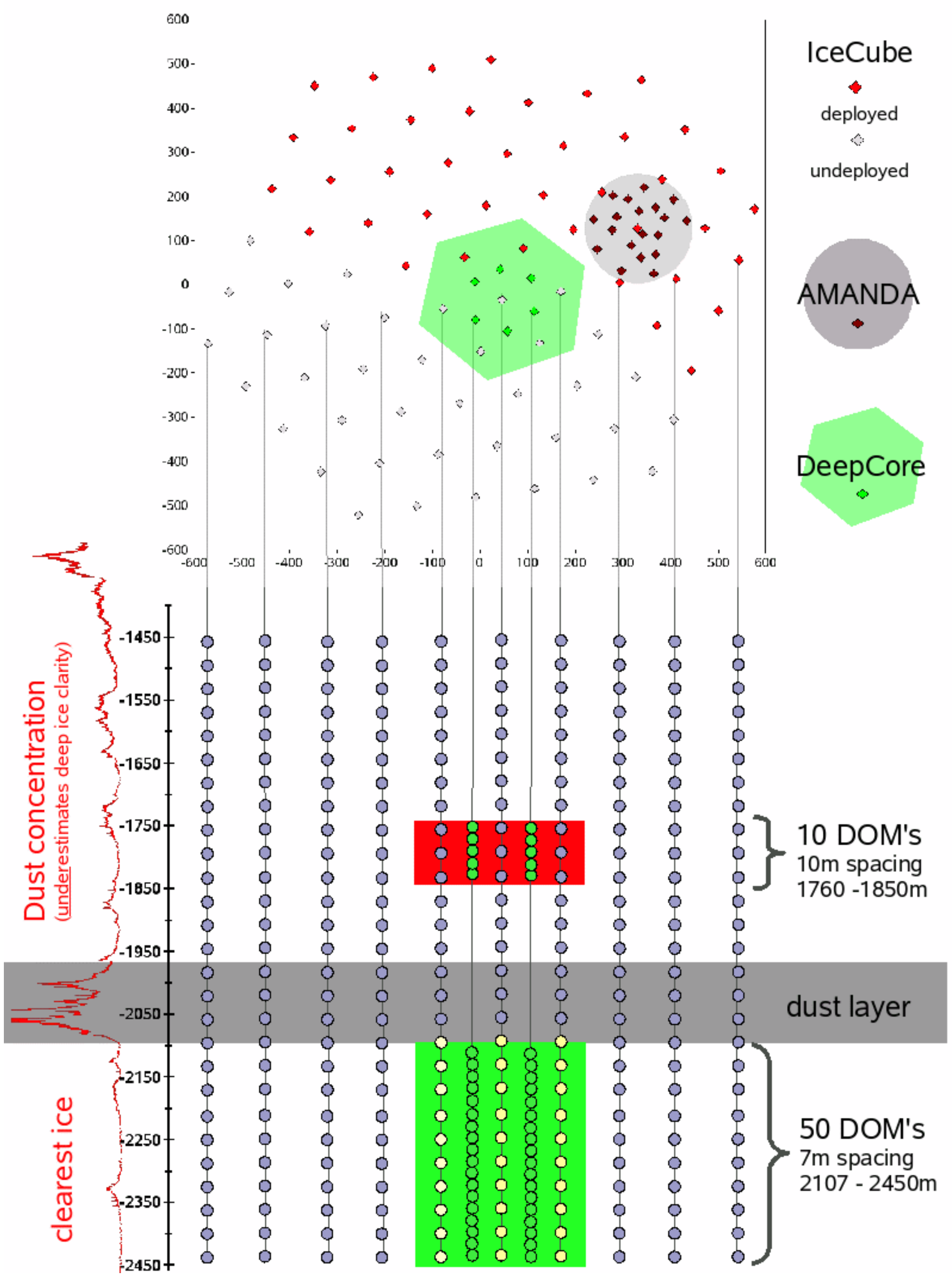
- Deployment over next 2 seasons (one string this season)

- 60 High Q.E. DOM
(in average +40% @ 405nm)

- 7m - 10m DOM spacing in very clear ice

- 13 string deep core array with interstring spacing of 72m

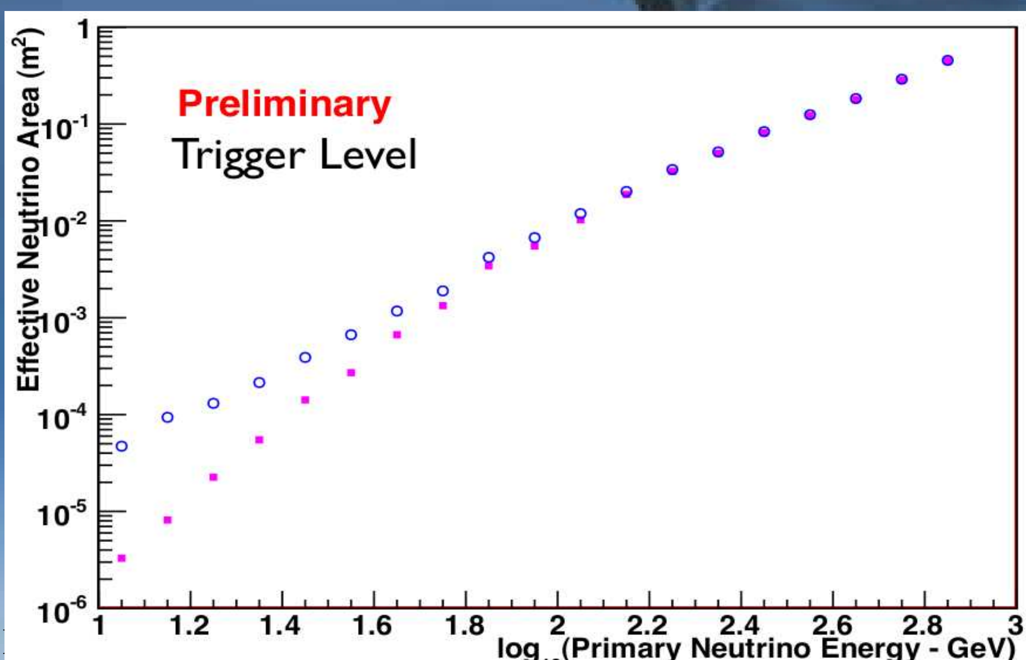
- Instrumenting a volume of $V = 0.025\ km^3$ (comparable to AMANDA-II)



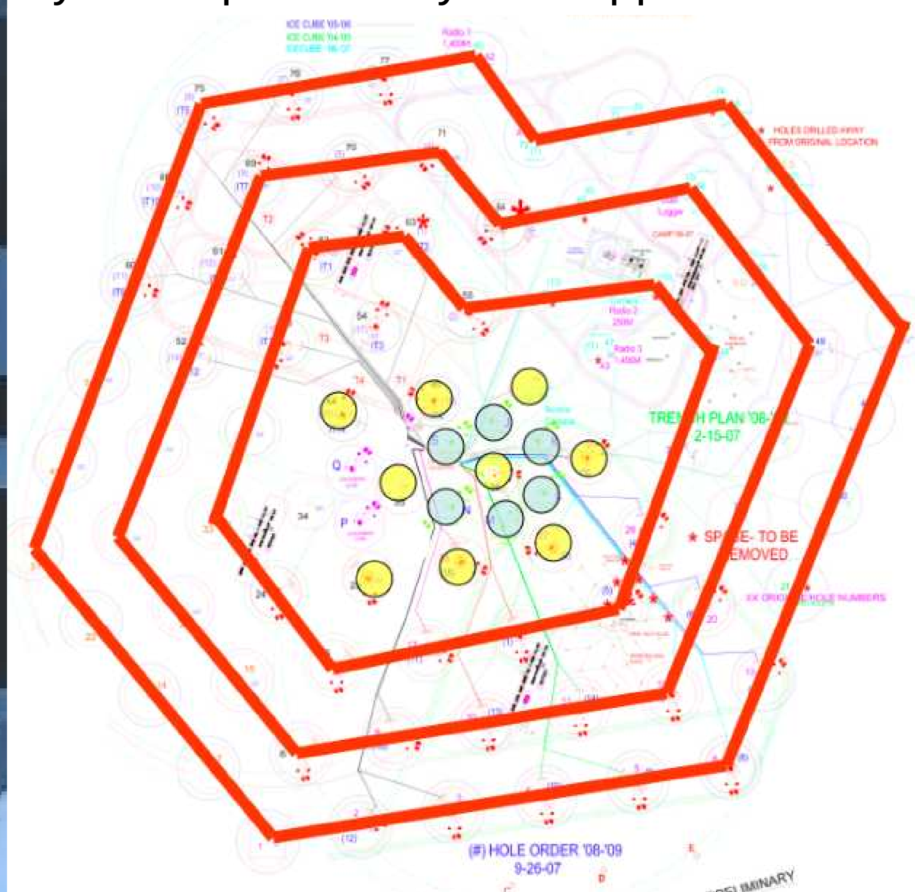
Low energy prospects:

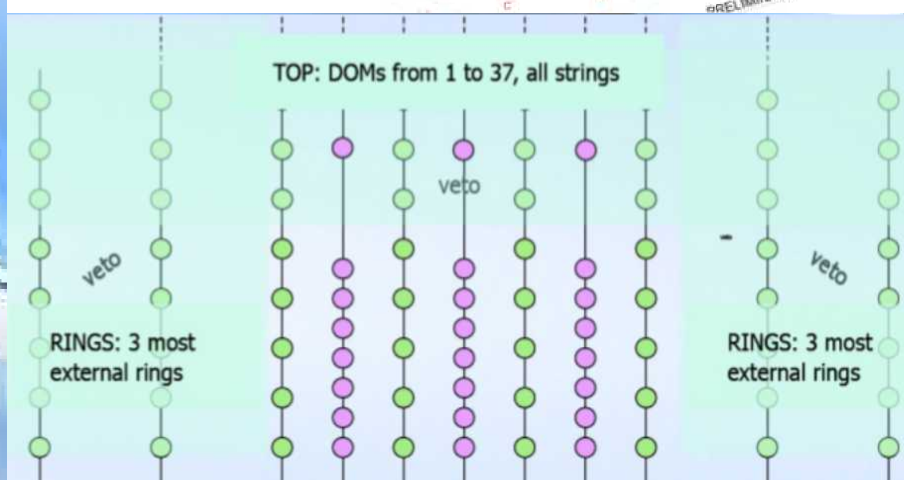
- ***IceCube Deep Core f*or improved low *E* neutrino detection capabilities (E_ν>few GeV)**
- **Multiple physics interests, most notably:**
- - WIMPs search extended to low mass & around the year
- - Oscillations studies (cascade/muon VS incidence and *E*)
- - Point sources in the Southern Sky / with steep spectra /
- LE cutoff at O(<10 TeV))

Currently, a simple VETO filter allows to
- Reject 99.99 % of the background (non contained events)
- Keep signal with 98 % efficiency
selecting only low energy events (<100 GeV)
<u>Goal:</u> Reach >10^6 rejection level



IC/DC <u>VETO:</u> Dense core surrounded by 3 complete IC layers + upper sensors



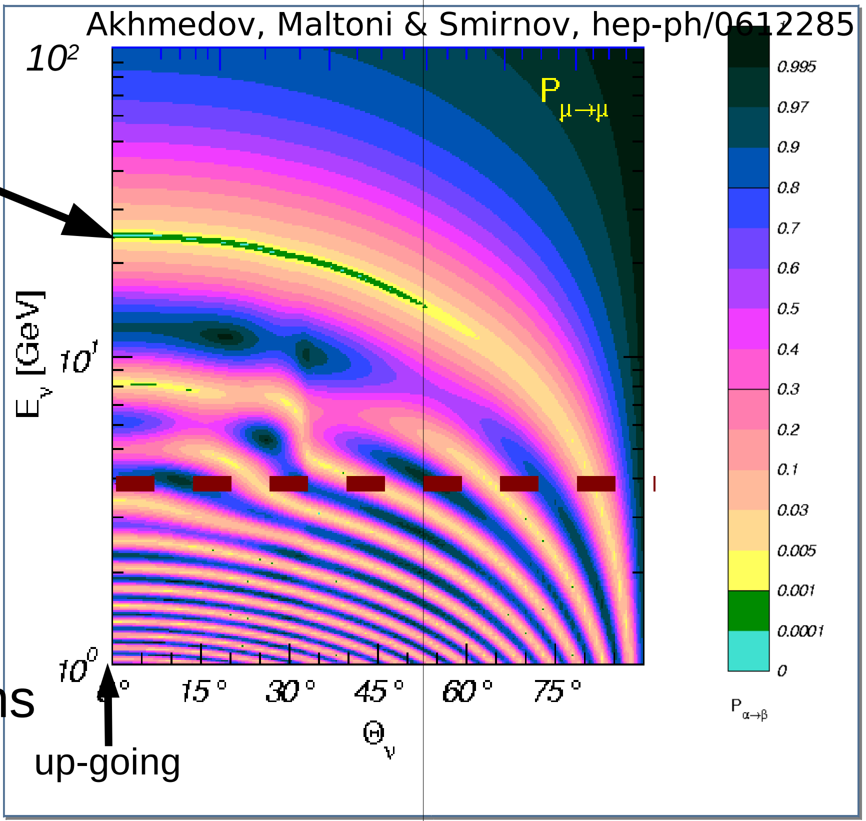


IC/DC **1year:** Early simulation studies

Threshold below 10 GeV
→ overlap with beam experiments,

Potential (optimistic view ?):
Standard oscillations measurements down to >1st dip could be measured:
- depending on our ability to distinguish shower from track events
- keeping high selection efficiency of contained events

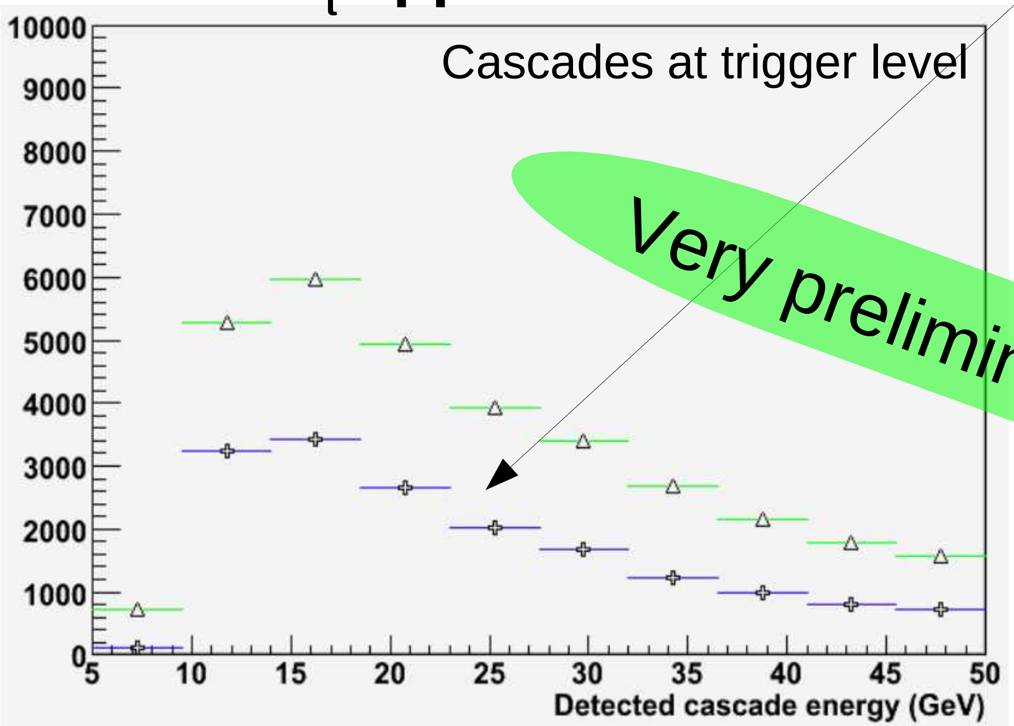
First dip



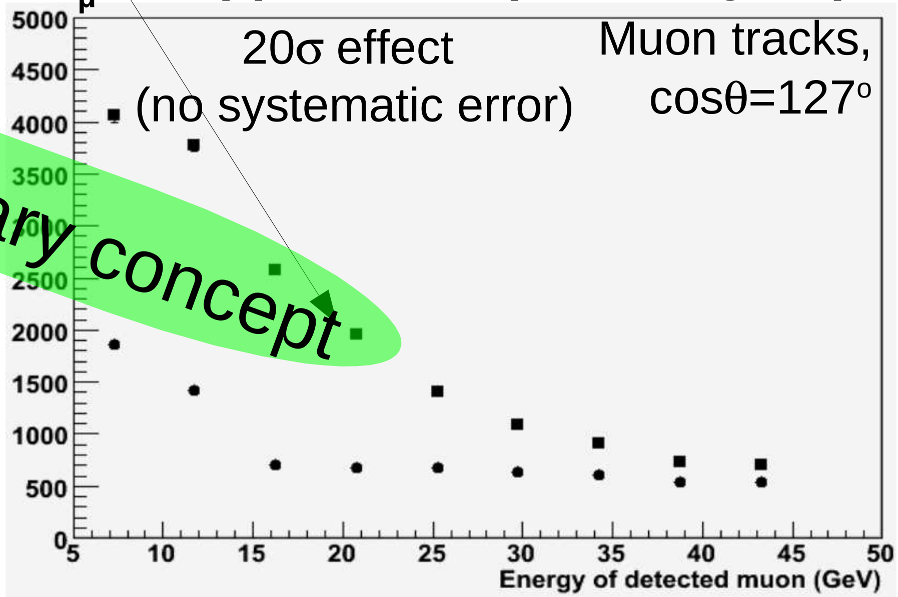
No oscillations

up-going

ν_τ appearance



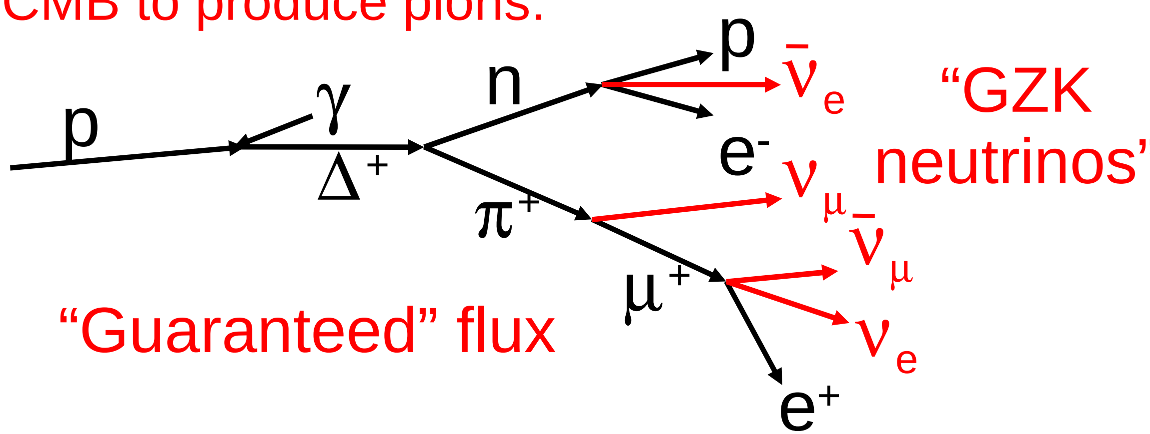
ν_μ disappearance (IC/DC 1 year)

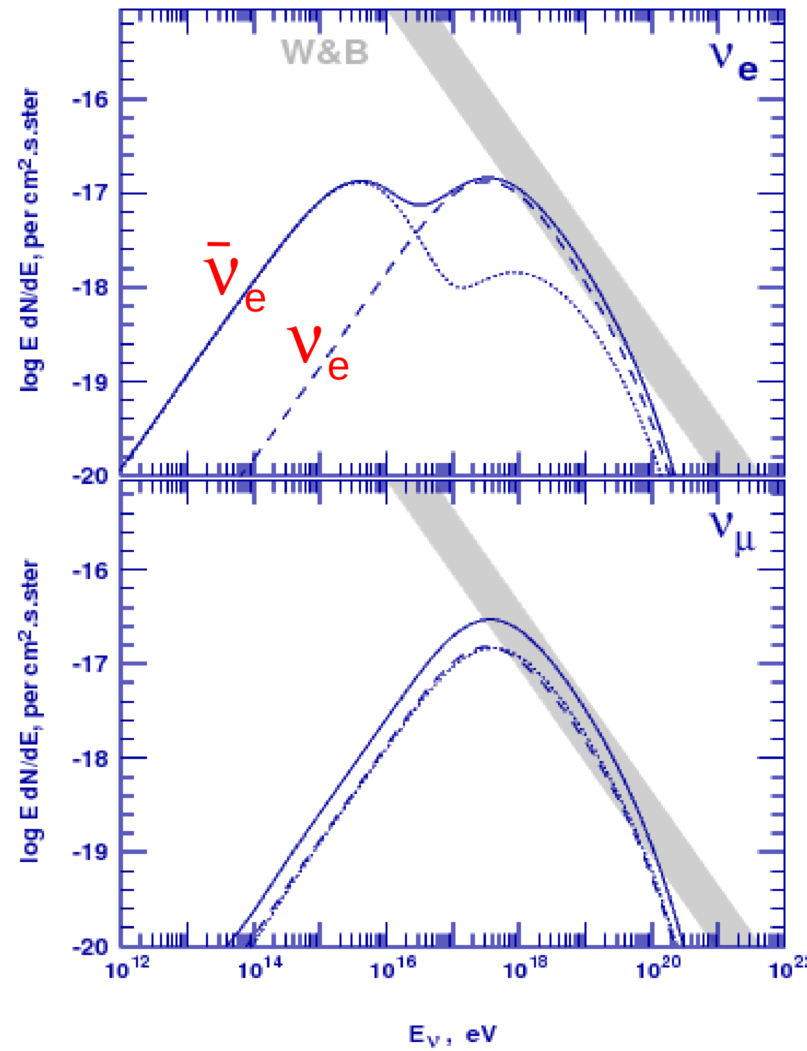


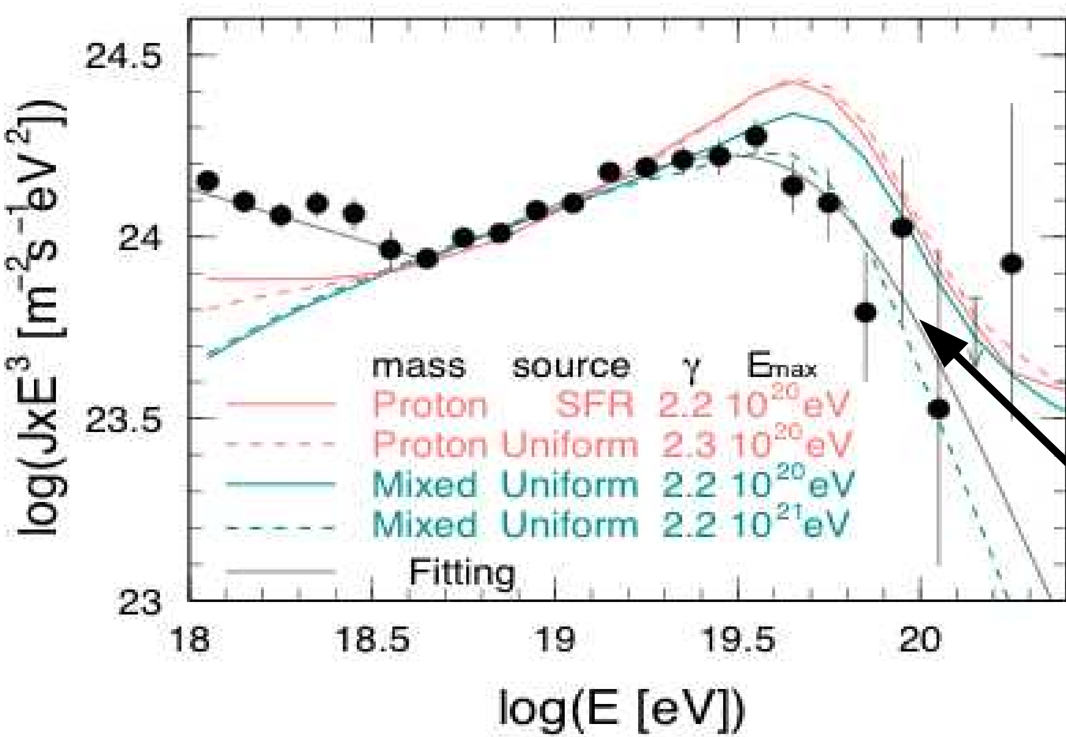
Very preliminary concept

Ultra High Energy Neutrinos: Is there a GZK cutoff ?

Above ~5 x 10^{19} eV, cosmic rays interact with CMB to produce pions:



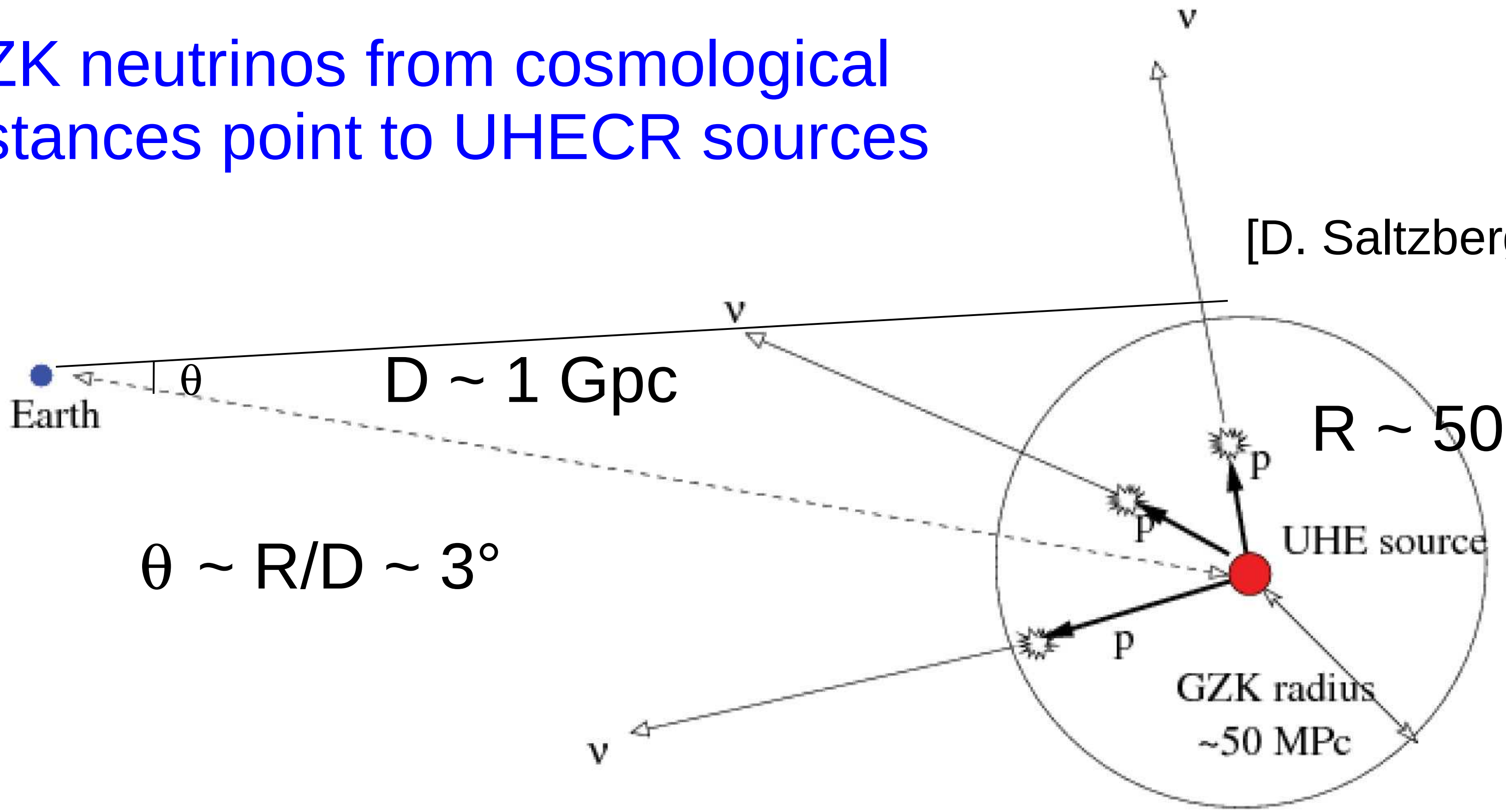




Auger 6 sigma steepening above $10^{19.7}$ eV --> GZK cutoff

GZK ν point to UHECR sources

GZK neutrinos from cosmological distances point to UHECR sources



[D. Saltzberg]

D ~ 1 Gpc

R ~ 50 Mpc

$\theta \sim R/D \sim 3°$

"GZK sphere"
of arbitrary B deflection / diffusion

Demultiplication of neutrinos: 10's per UHE proton
0.1-1% GZK neutrino interaction prob. in 1 km of ice

Ultra High Energy Cosmic Rays

Recent AUGER elongation rate measurements not compatible with a all-proton UHE CR composition, leading to a reduction of the cosmogenic flux.

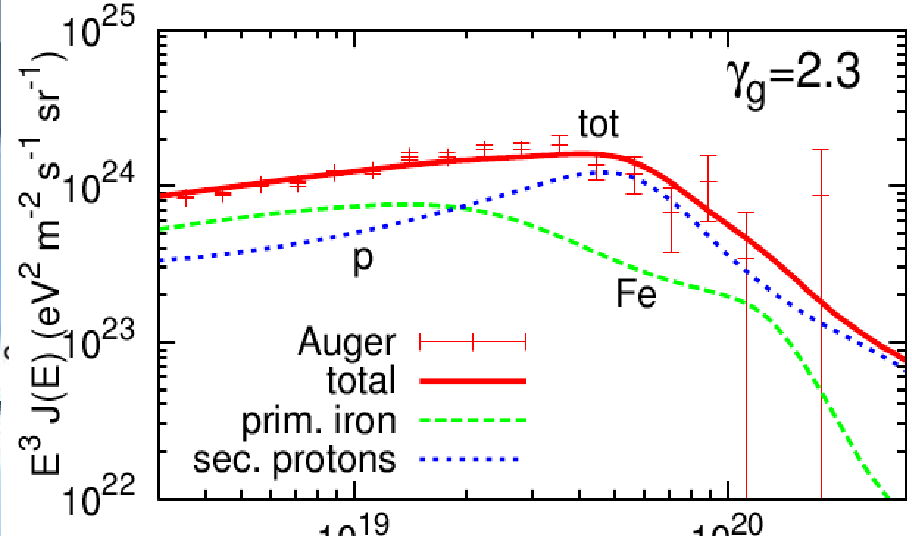
Observations are still consistent with:

- Proton dominated with small admixture of heavy nuclei --> essentially of the order of ~0.1 - 1 event / km3 / yr (muons + showers) (Anchordoqui et al)
- All intermediate mass – all heavy nuclei composition --> suppression by up to 2 orders of mag. : 0.01 – 1 / km^3 / yr, depending on injection spectra (cutoff, spectral index)

Note however that:

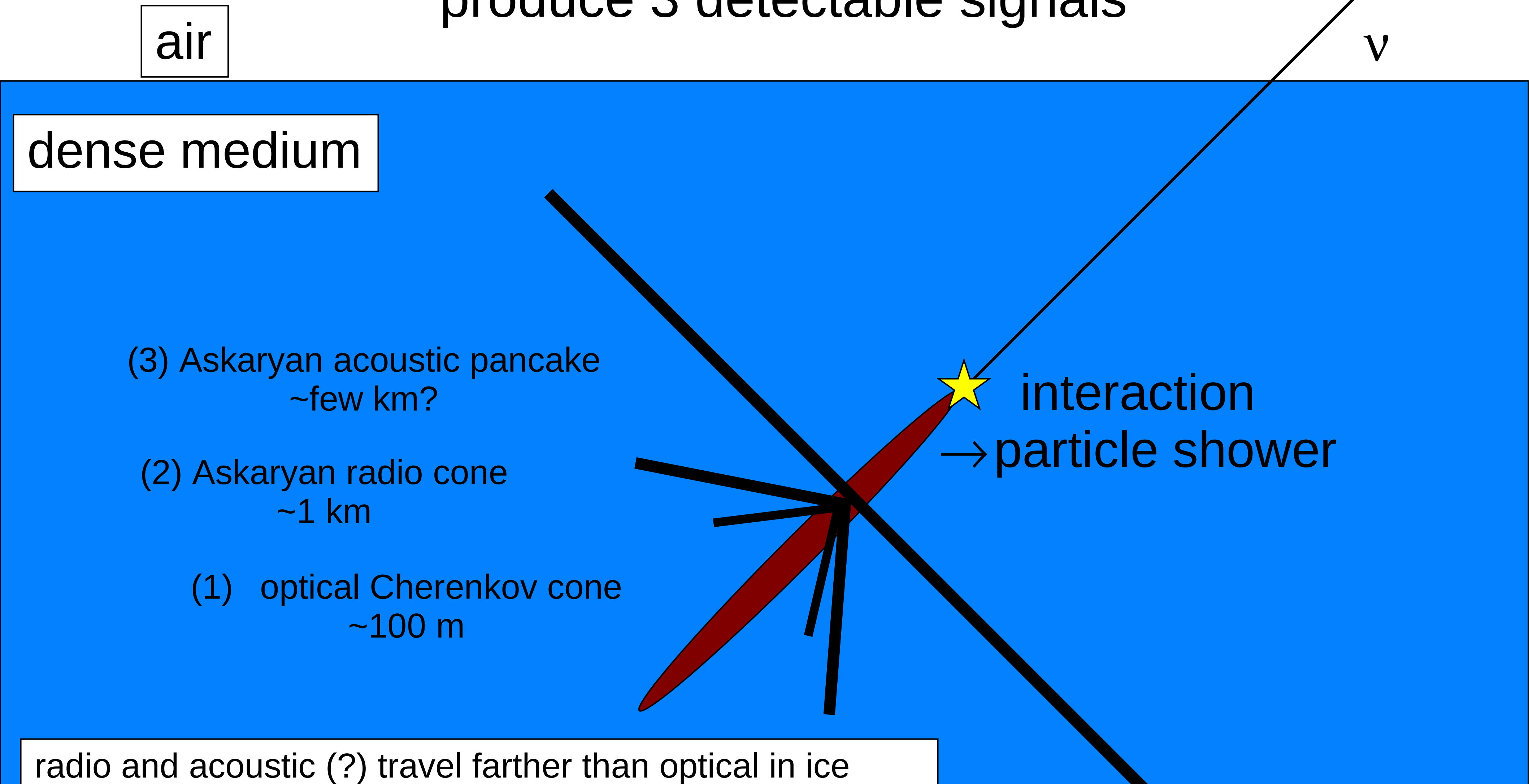
- AUGER UHECR anisotropy favor proton-dominated composition
- Protons should start to dominate above $\approx E_{GZK}/2$, $\forall$ primary component, as AUGER favors "flat" injection spectra

Pure iron primary flux: $E_{max} = Z_0\ 10^{21}$ eV



(after Aloisio, Berezinski, Gazizov)

Neutrino-induced cascades produce 3 detectable signals



radio and acoustic (?) travel farther than optical in ice

Acoustic signal strength: $\gamma = c^2\beta/C_P$ (Gruneisen parameter)

- γ ice ≈ 7.3 γ sea,
- salt impure + expensive drilling (γ salt ≈ 2.5 γ ice)

TA equation:

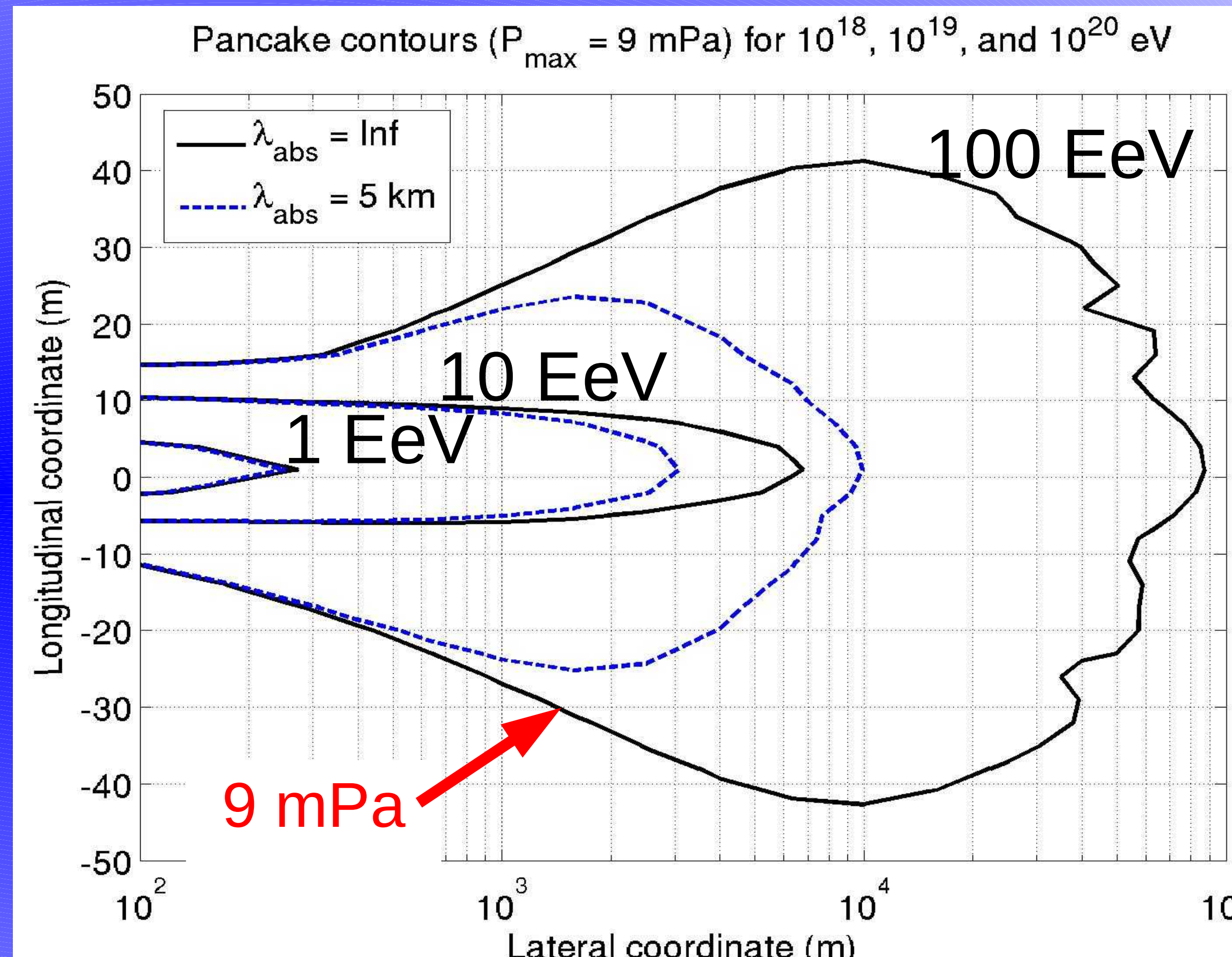
$$\rho_0 \vec{\nabla}\cdot\left(\frac{1}{\rho_0}\vec{\nabla} p\right) - \frac{1}{c^2}\frac{\partial^2 p}{\partial t^2} = -\frac{\alpha}{C_p}\frac{\partial^2 q}{\partial t^2}$$

Acoustic radiation pattern in ice

- Sensor sensitivity
- Exploit coincidences

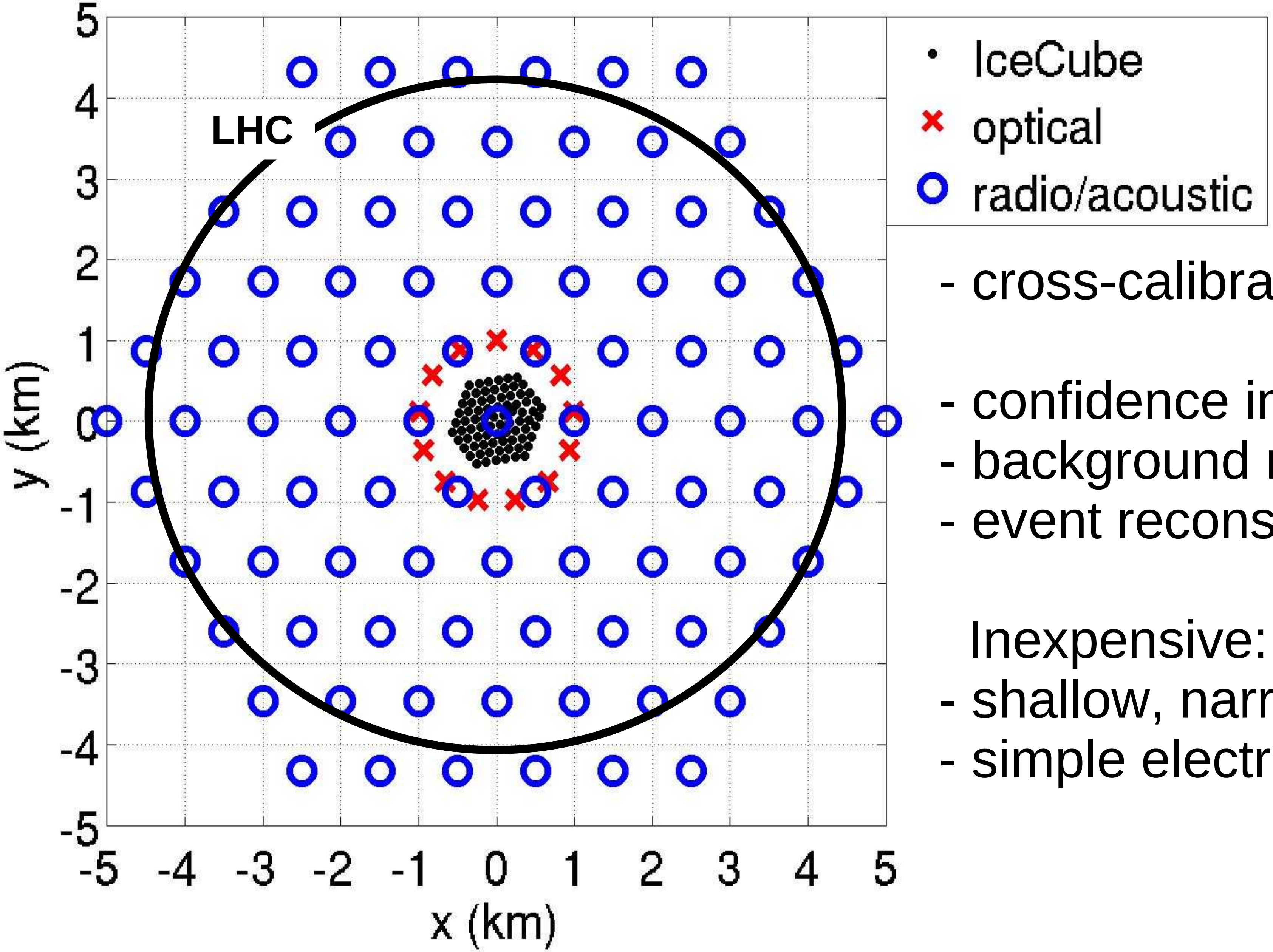
are most important:

- Release of sensor spacing on a string
- Reduce electroinic noise rate
- Increase number of hit channels
- Lower the energy threshold



E.g. 10^{18} eV with close to ~100% detection efficiency (1km string spacing, 5m between sensors geometrical configuration, >2 string pancake geometry) can be reached given 1 mPa threshold (in absence of anthropogenic / local sources of noise)

S. Pole good for all 3 methods (optical, radio, acoustic)
Build a hybrid array!
Goal: detect ~10 - 100 GZK ν in a few years



- cross-calibration

- confidence in signals
- background rejection
- event reconstruction

Inexpensive:
- shallow, narrow holes
- simple electronics

The South Pole Acoustic Test Setup (SPATS)

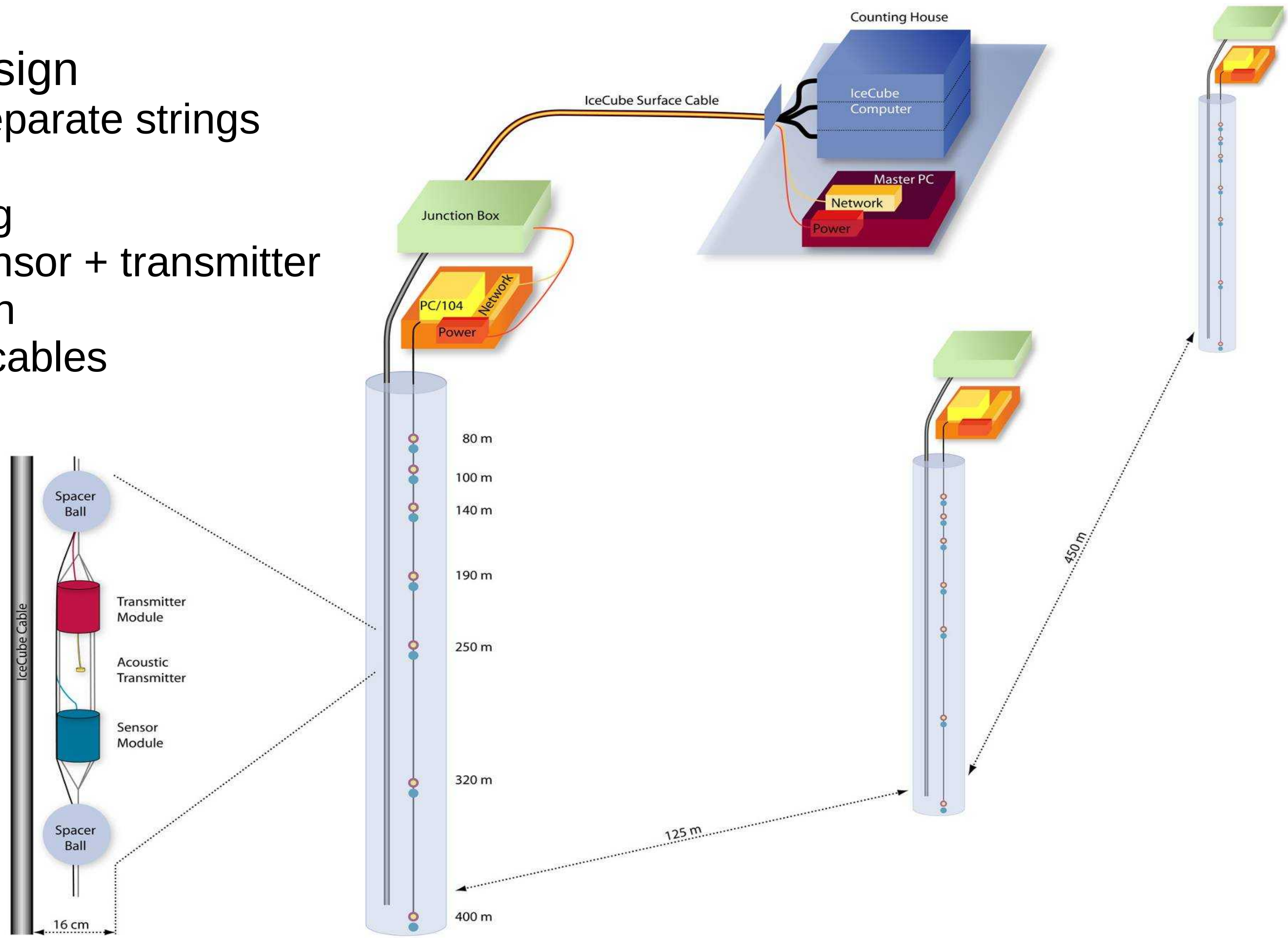
First step toward large acoustic/hybrid detector at South Pole aiming at the measurement of the ice properties in situ:

- Attenuation lengths, noise floor, sound speed vs. depth,

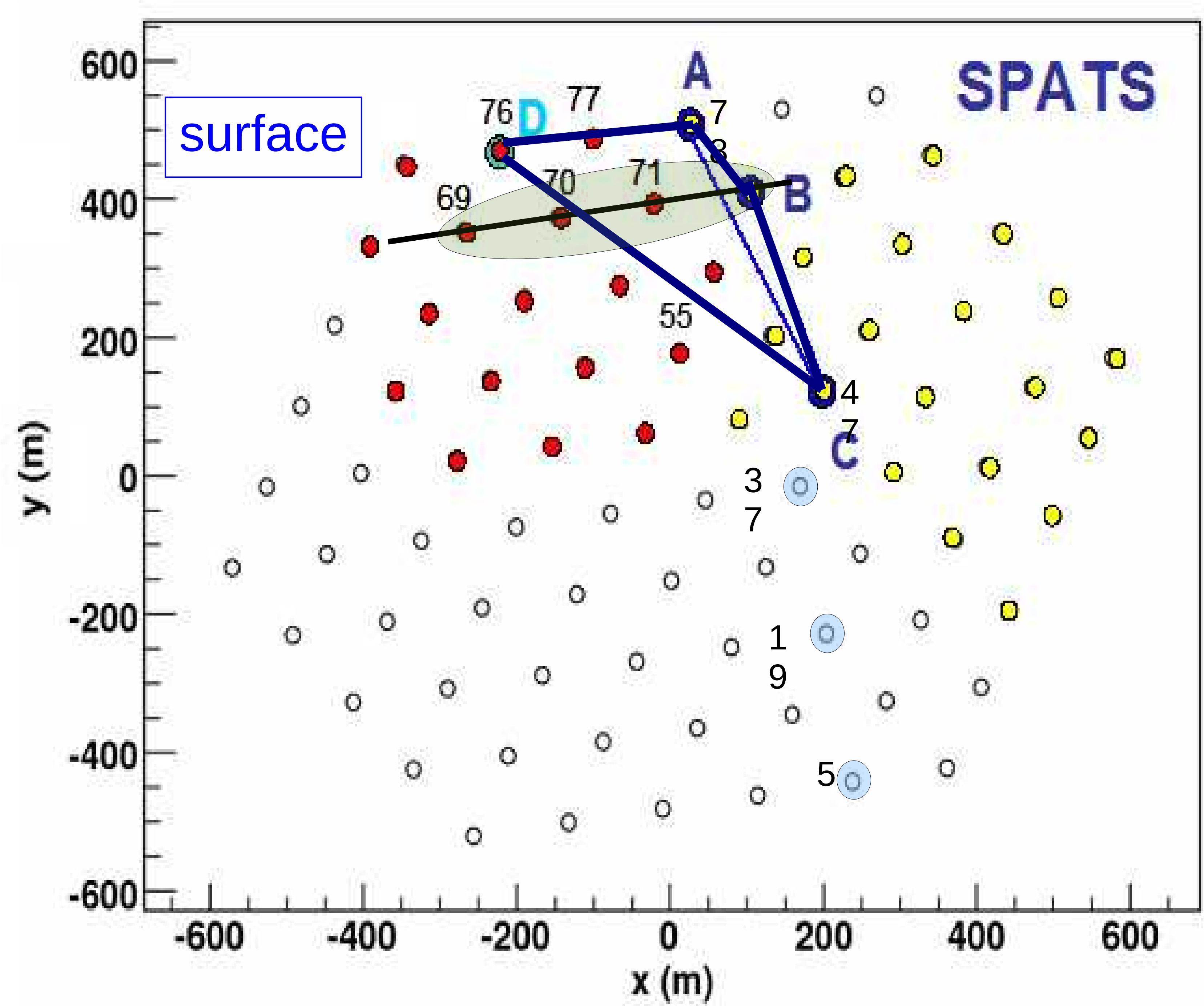
transients events (our background: stick/slip glacier movement or bulk ice cracking)

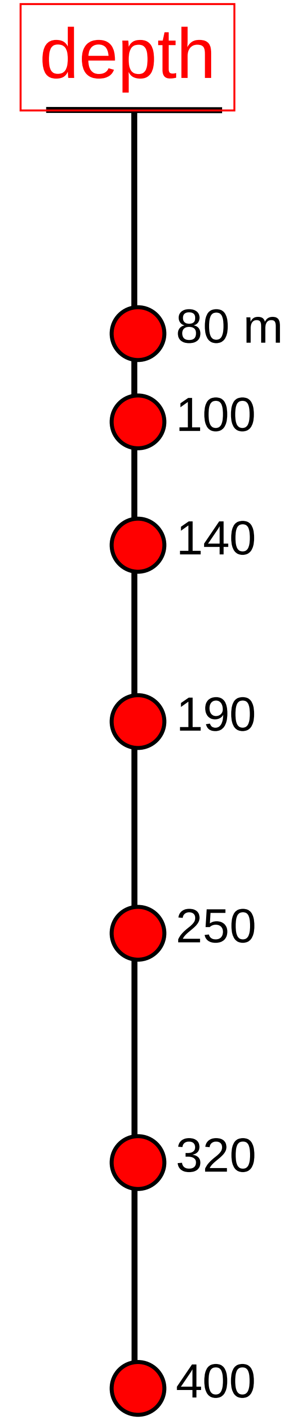
SPATS Array Design

- IceCube holes, separate strings
- 4 strings
- 7 stages per string
  - 3 channel sensor + transmitter
- surface digitization
- IceCube surface cables



SPATS geometry





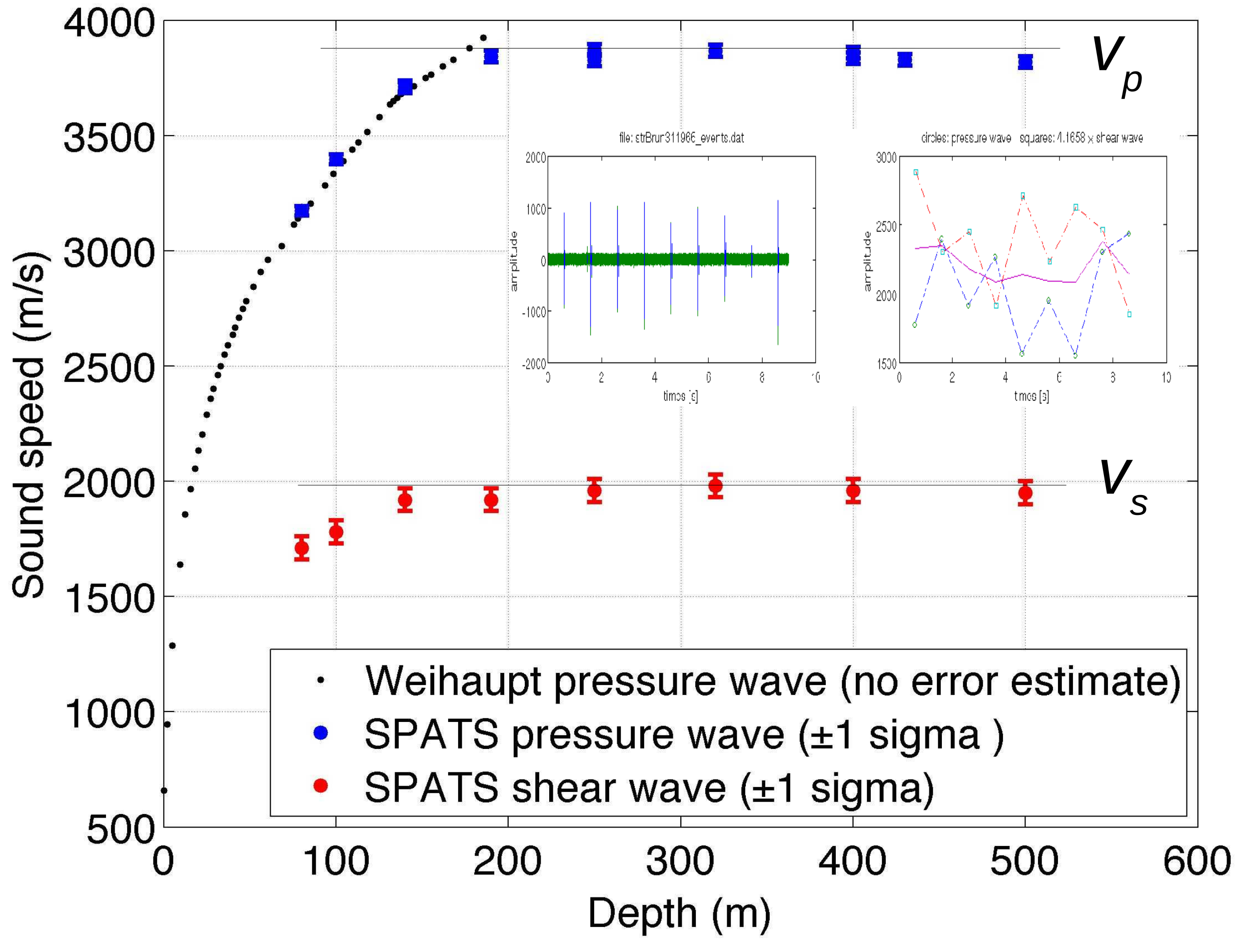
Measurement of pressure and shear wave speed vs. depth with SPATS + Pinger

- Sound speed in water from adiabatic bulk modulus *K*

- P-wave sound speed from *M* (P-wave elastic modulus)

-S-wave sound speed from G (rigidity modulus)

As Poisson's ratio is very close to 1/3 for ice, $M \cong 4G$ (more precisely: $v_p = 1.985\ v_s$)



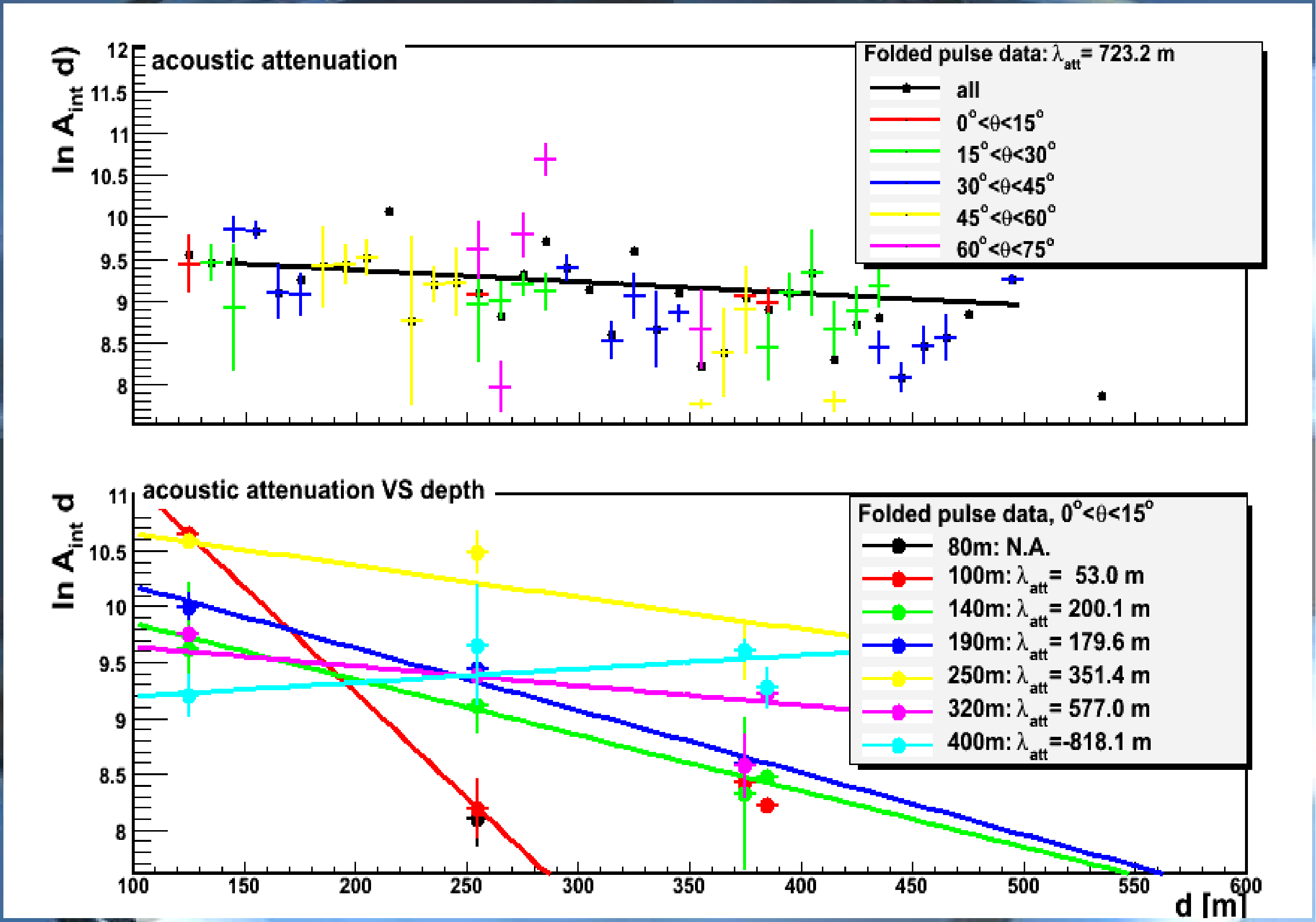
At the hole water-ice interface, P-waves are partly reflected, S-waves are generated (with amplitudes depending on the incidence angle).

Attenuation Length

Analysis in frequency domain with pulse time with noise suppression and pulse resynchronisation by convolution

Main preliminary result:
Hints at an increase of the attenuation length with depth to level which could be sufficient to ensure the viability of the detection technique in SP ice

The analysis escapes many sources of systematic uncertainties, when using horizontal baselines, but statistics is too low for firm conclusions



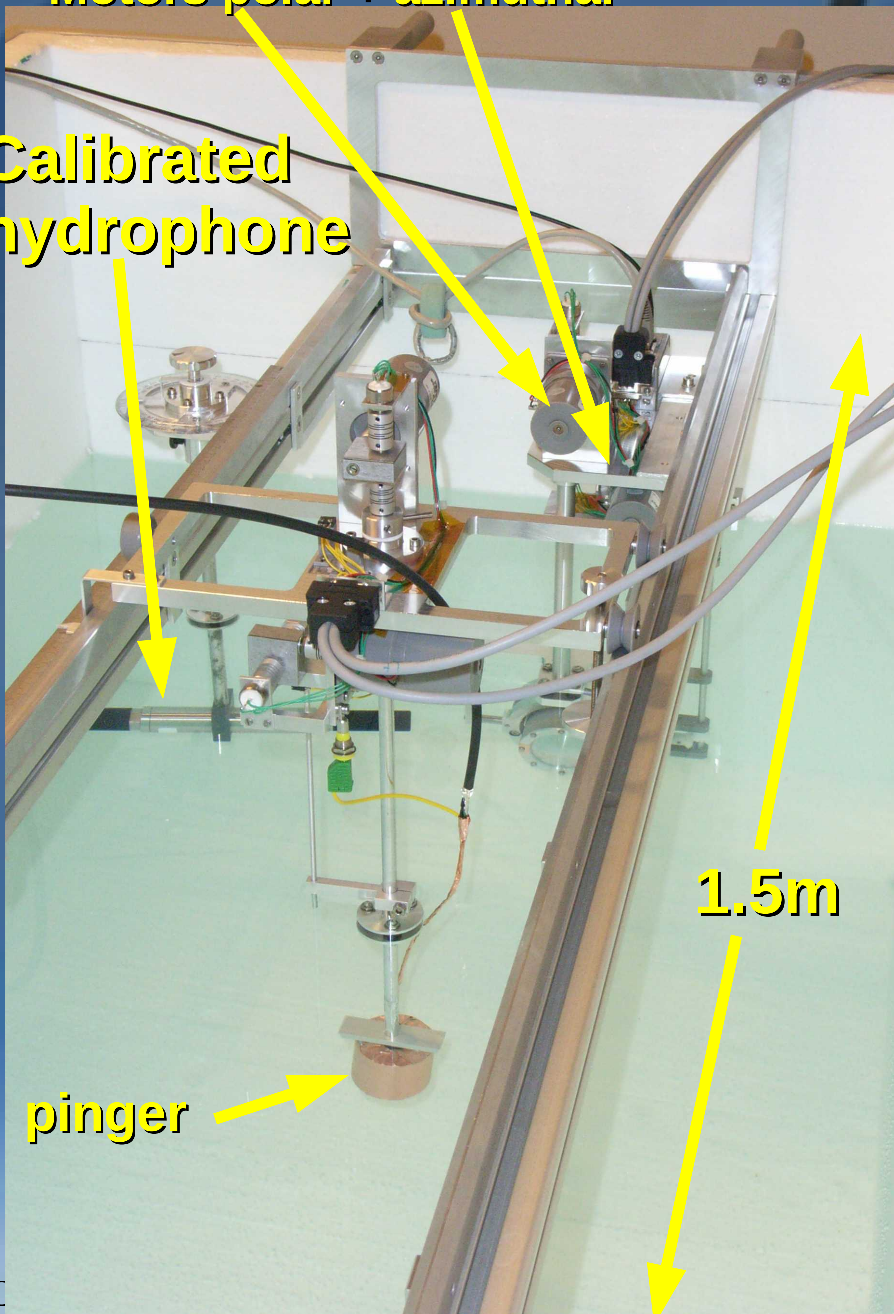
--> Next pinging campaign this season:

- Increased statistics: pinger with increased repetition rate
- Probe baseline distance between 140 – 1000 m

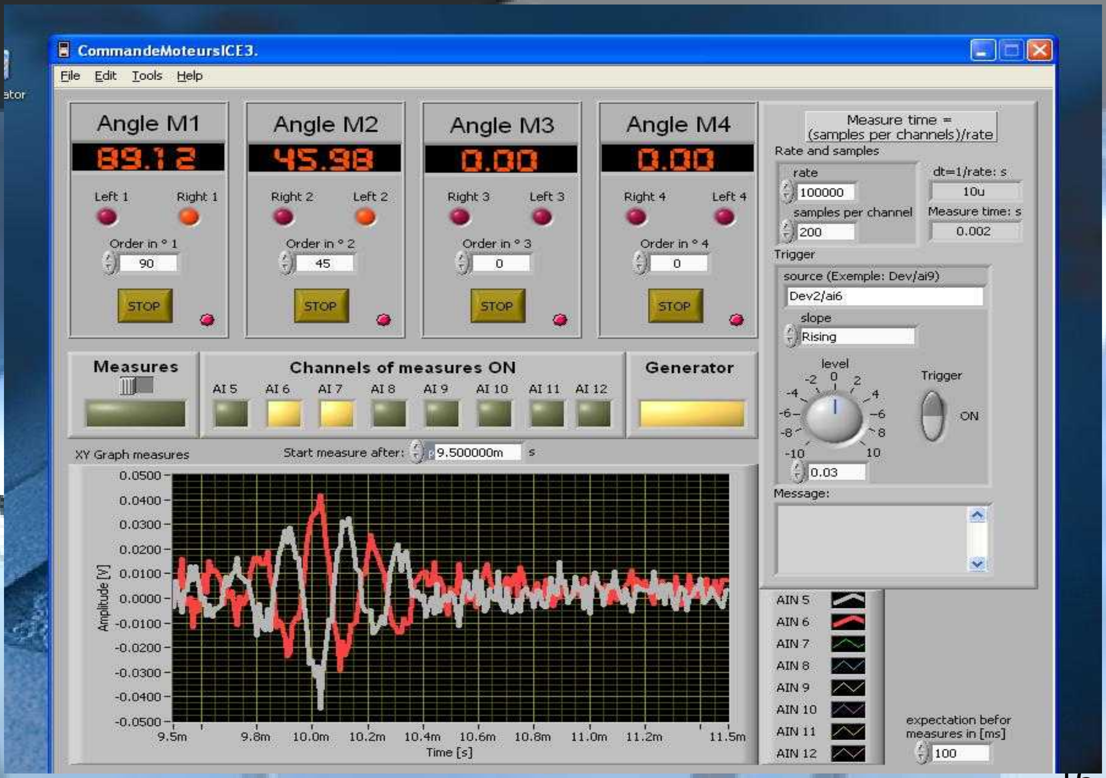
Acoustic R&D

Acoustic test setup
Sensor design

The setup consists of a support structure for two sensors and one emitter in a water tank



Automated relative orientation for characterization of the acoustic emission / sensing profiles (NI card interfaced to a PC running LABVIEW)



Home made sensor (old electronics)

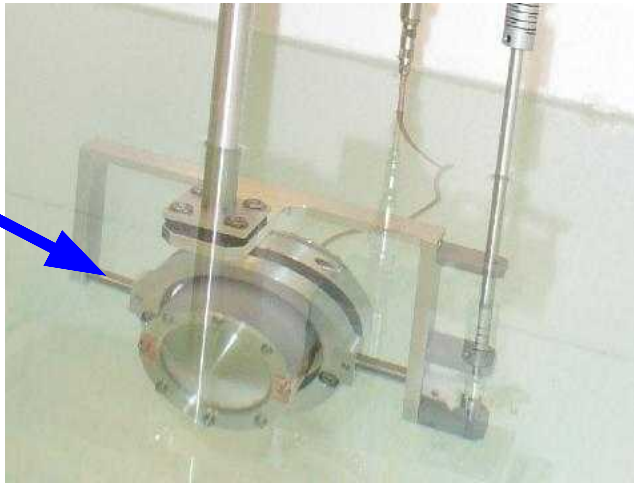
Noise level: ~11.5 mPa (3μV at input)

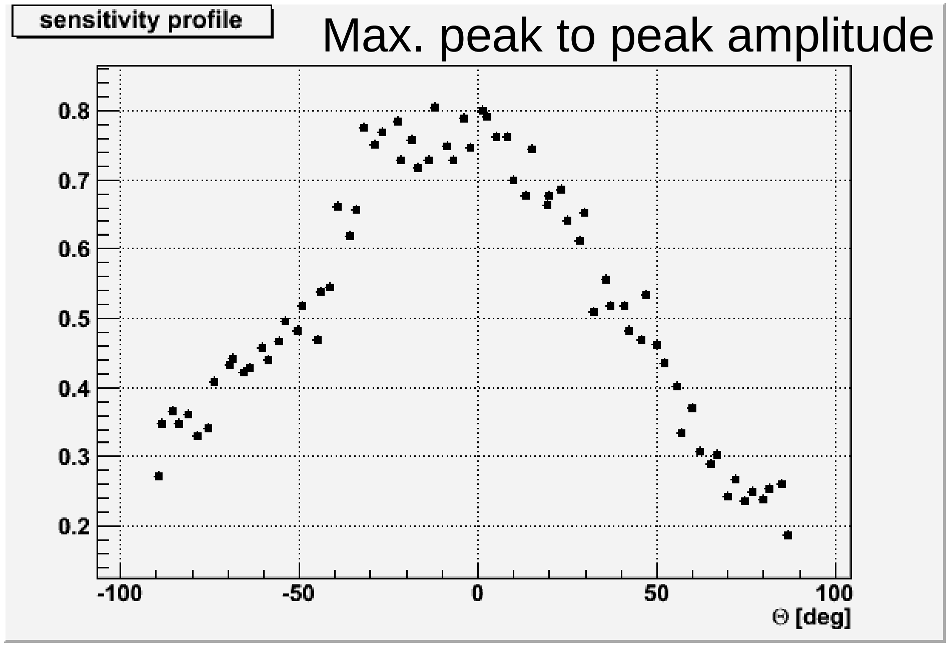
Sensitivity: -113 dB re V/μPa (@ 30 kHz)

U=3μV on the piezo alone would correspond to 54 mPa (d_{33}=330·10^{-12} C/N, C_{pzt}=470 pF → $Q = C_{pzt}$ x 3μV = 8800 e → $p = C_{pzt} U / (d_{33}\ S_{pzt})$), therefore **demonstrating the acoustic lense** (also transmission loss from non perfect impedance matching)

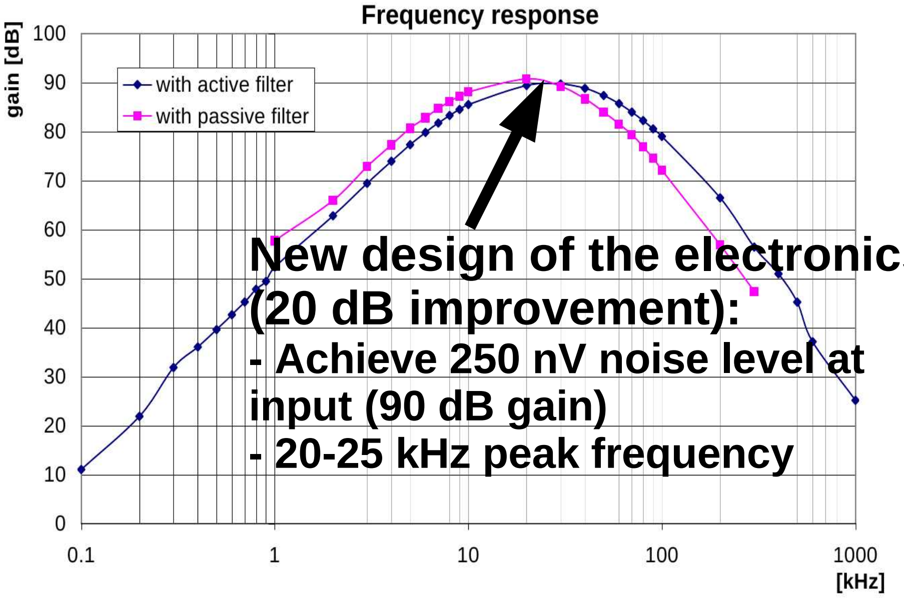
Calibrated hydrophone

- noise level ~50 mPa (0.25 mV)
- -166 dB re V/μPa





New: a mPa noise level sensor



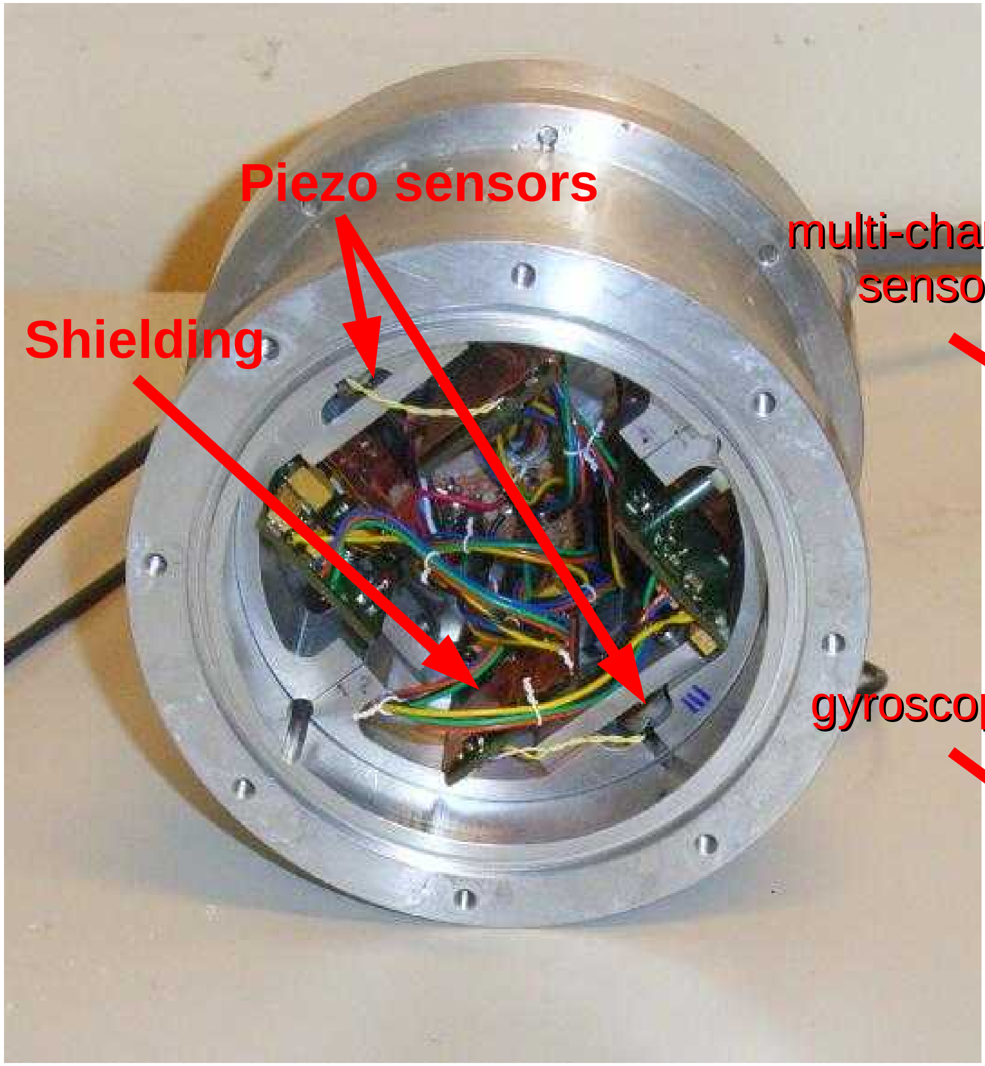
Multi-channel sensor: 1st version built

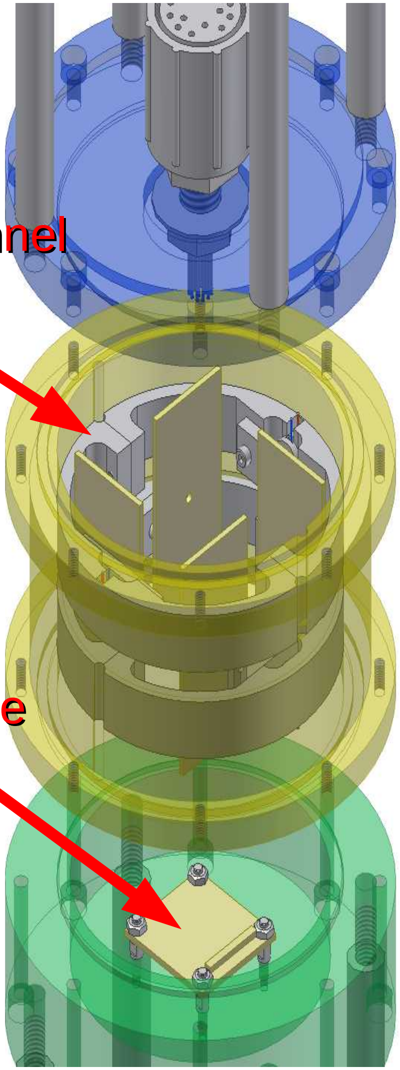
- Aluminium structure:
  4.8 km/s,
  $Z_{alu}=\rho c$ = 17.3 Mrayls $\cong (Z_{PZT}Z_{ice})^{½}$

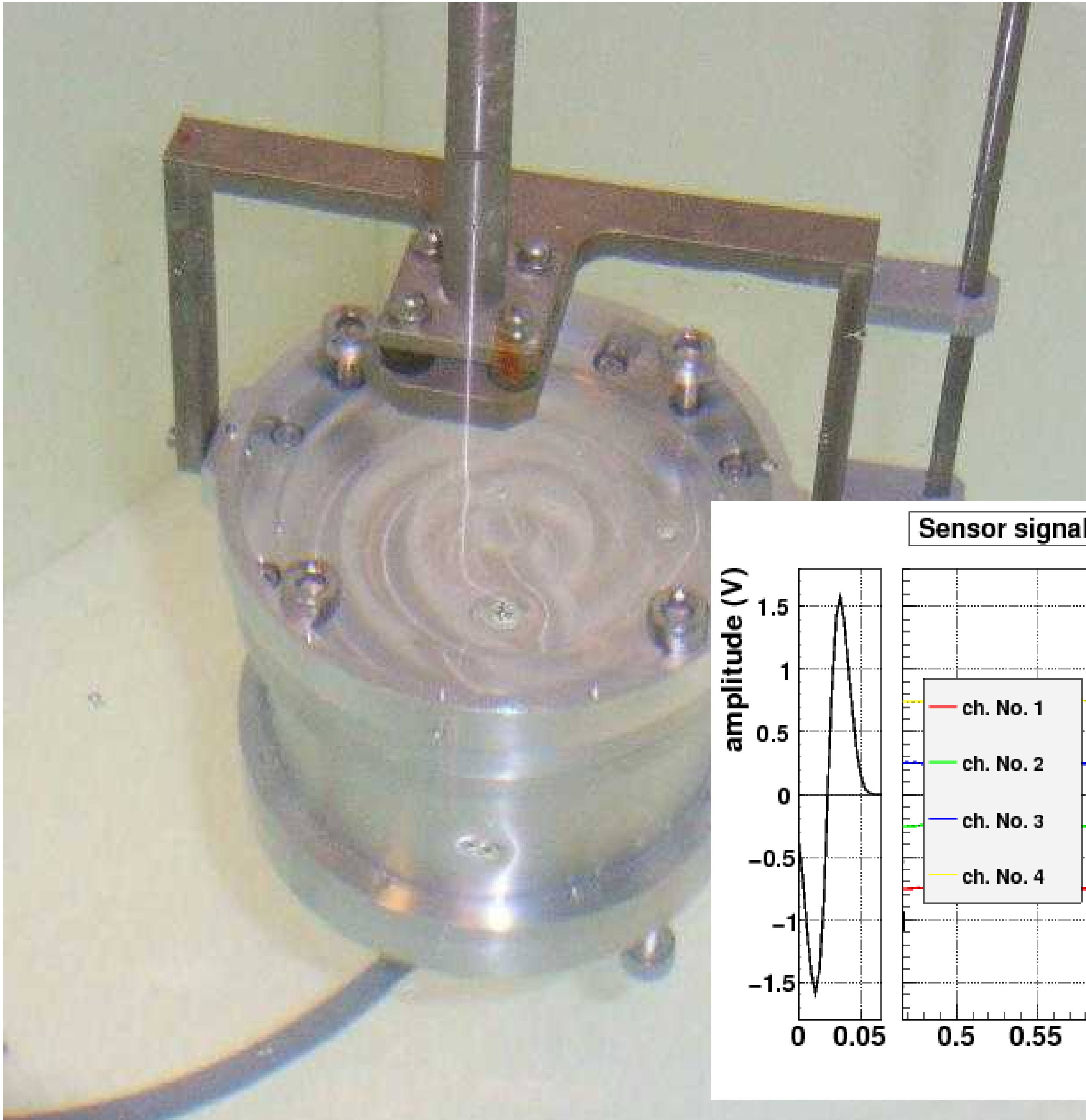
- Equipped with new electronics:
  ≅3 mPa equivalent noise pressure level
- Consumption ~ 3W
- Digital electronics not yet included

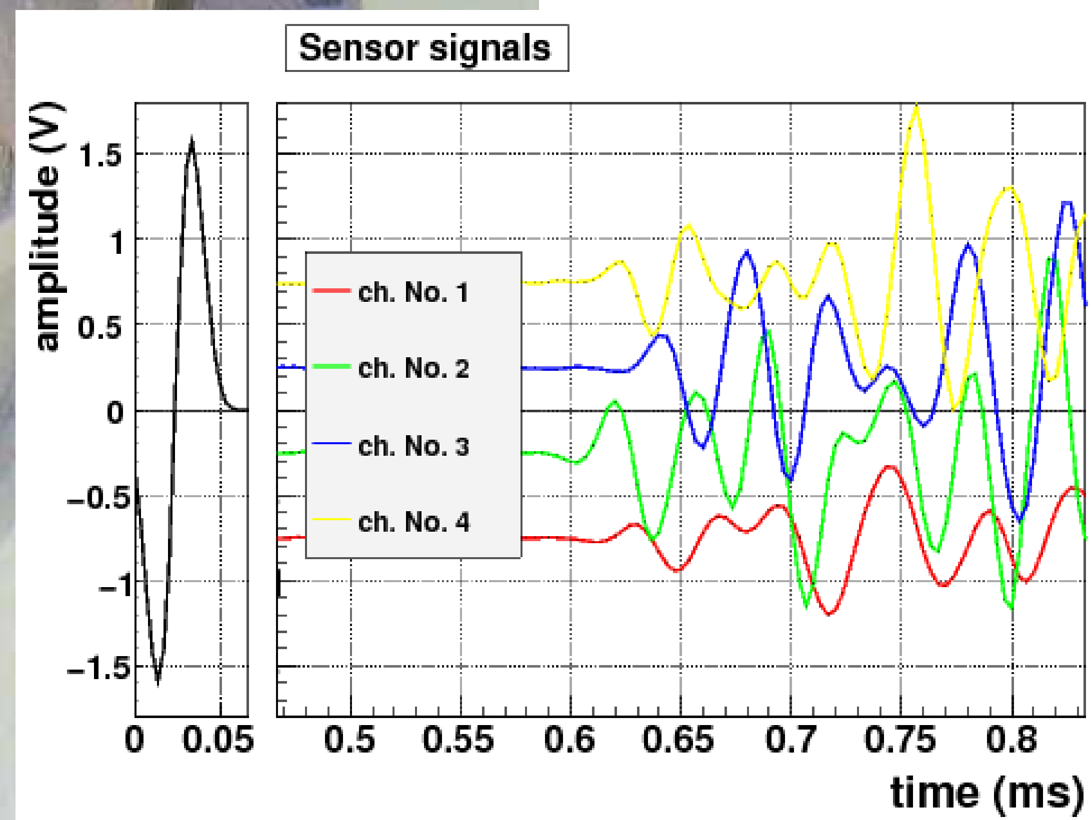
Aim at proposing a realistic design:

- **Signal transmission to 1.5 km**
- **Module (via channel coupling) & array (via triangulation) trigger**
- **Low consumption**
- **Adapted for low cost manufacture**









Sensor signals
amplitude (V)
1.5
1
0.5
0
−0.5
−1
−1.5
0
0.05
0.5
0.55
0.6
0.65
0.7
0.75
0.8
ch. No. 1
ch. No. 2
ch. No. 3
ch. No. 4
time (ms)

Triangulation

Time resolution is essential:

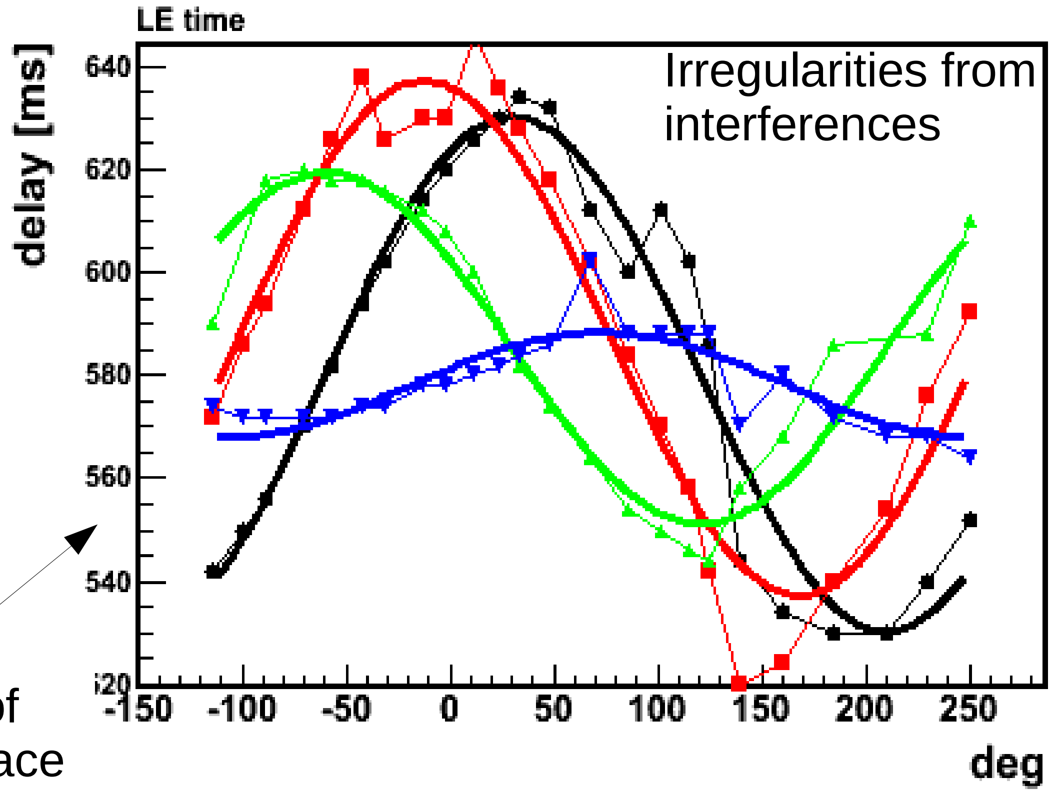
- 100 kHz is required (to reach cm resolution in alu). Fortuitous match to the necessary signal sampling rate digitization frequency

- Good coupling between all channels (average factor 2 amplitude variations over 180^{o} rotation is observed)

Goal:

0.5-5 µs pulse start time resolution (depending on amplitude) should correspond roughly to 2-20^{o} ($4\pi/10^2$ - $4\pi/10^4$) angular resolution with the current multi-channel sensor

→ may lead to efficient trigger concept at the sensor and at the array levels



Coupling problems between elements of the sensor → need special care for surface

Acoustic summary:

Good progress in reaching lower electronic / setup noise since June:
we have reached mPa noise level !

A second design optimization phase is necessary:

- Materials (impedance matching)
- Piezo with improved sensitivity
- Electronics (higher gain, lower noise)
- Improvement of the surface coupling between elements

Preliminary trigger study:

- Triangulation with multi-channel sensor
- Designing a digital acoustic board:
  - Multiplexed 300 kHz / ch (10 bits) digital readout + memory (no DSP)

Next:

- **Test noise at low T, high pressure**
- **Perform tests in larger environment (pool & Geneva lake):**
  - Avoid interference patterns from bath wall reflexions
  - Test of the logistics, appropriateness of the design

EPFL will continue taking part to the pinger analysis

The SPATS / IceCube collaboration is pursuing its effort in order to measure the SP ice absorption length with a new “pinging” campaign over an extended range of baseline distances this winter and eventually discuss of the opportunity for the deployment of a giant array (radio-)acoustic array

Conclusions

GeV neutrinos:

Potential seems extremely promising

EeV neutrinos:

Possibly in the reach of IceCube within a few years

Radio / acoustic detection techniques R&D on-going activities:

- Further developments, progress and tests are necessary to reach a noise level corresponding to $E_\nu = 10^{18}$ eV @ 1km threshold
- Characterizing the ice is a major target
- Establish a viable scenario for the deployment of a giant array