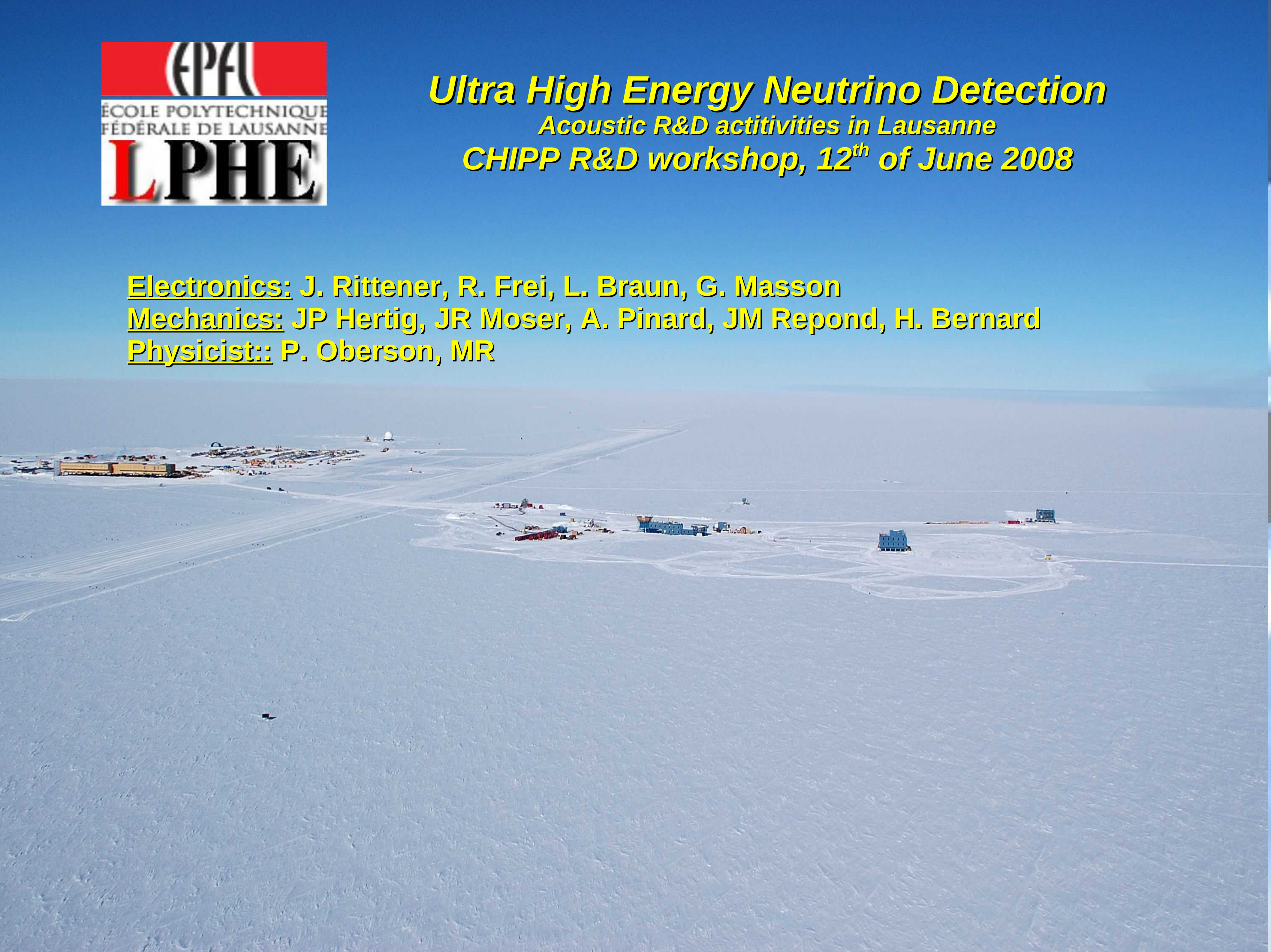


Ultra High Energy Neutrino Detection

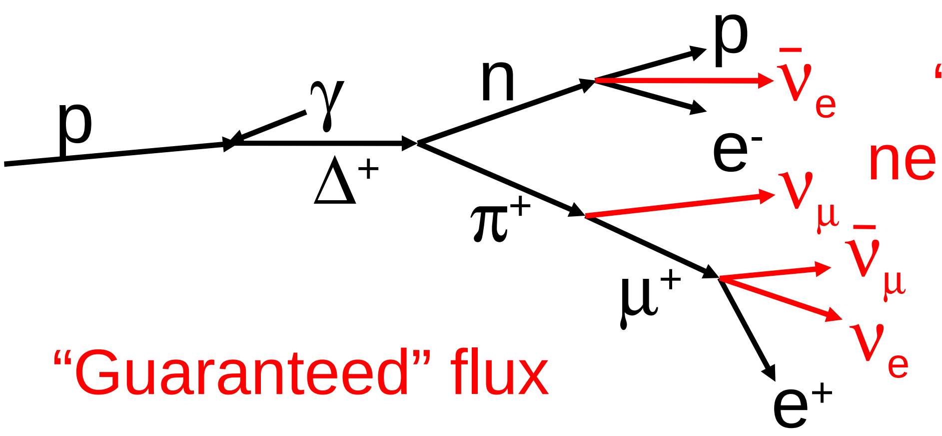
Acoustic R&D actitivities in Lausanne

CHIPP R&D workshop, 12th of June 2008

Electronics: J. Rittener, R. Frei, L. Braun, G. Masson
Mechanics: JP Hertig, JR Moser, A. Pinard, JM Repond, H. Bernard
Physicist:: P. Oberson, MR

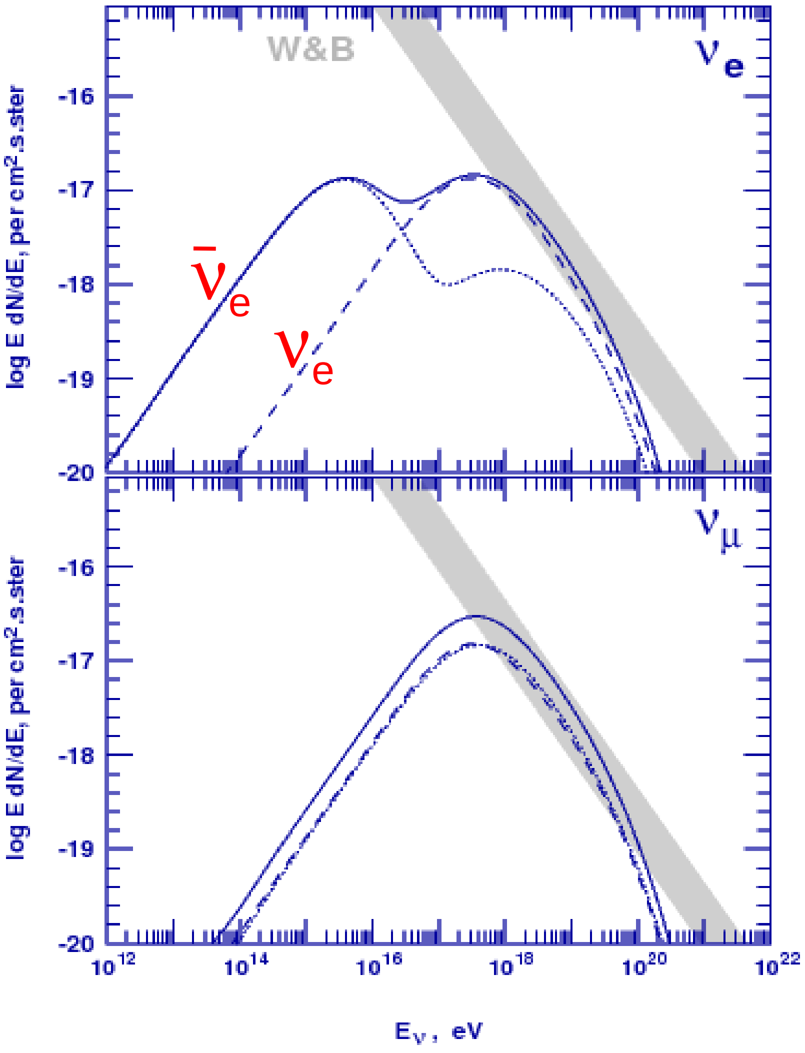
Is there a GZK cutoff?

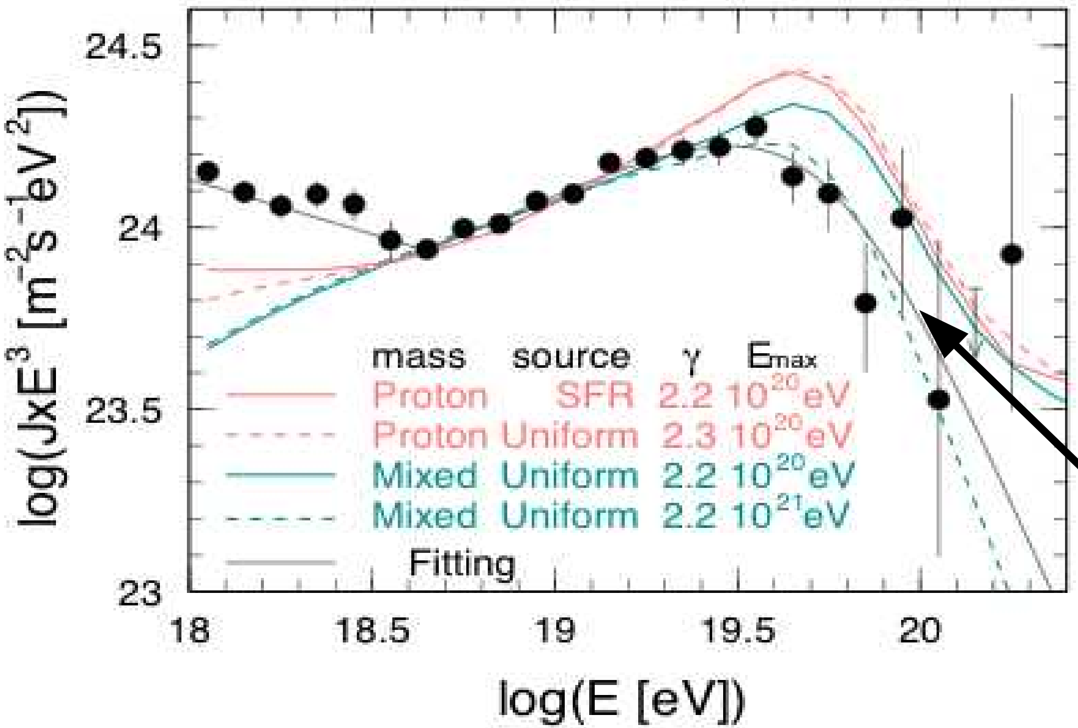
Above ~5 x 10^{19} eV, cosmic rays interact with CMB to produce pions:



"GZK neutrinos"

"Guaranteed flux"

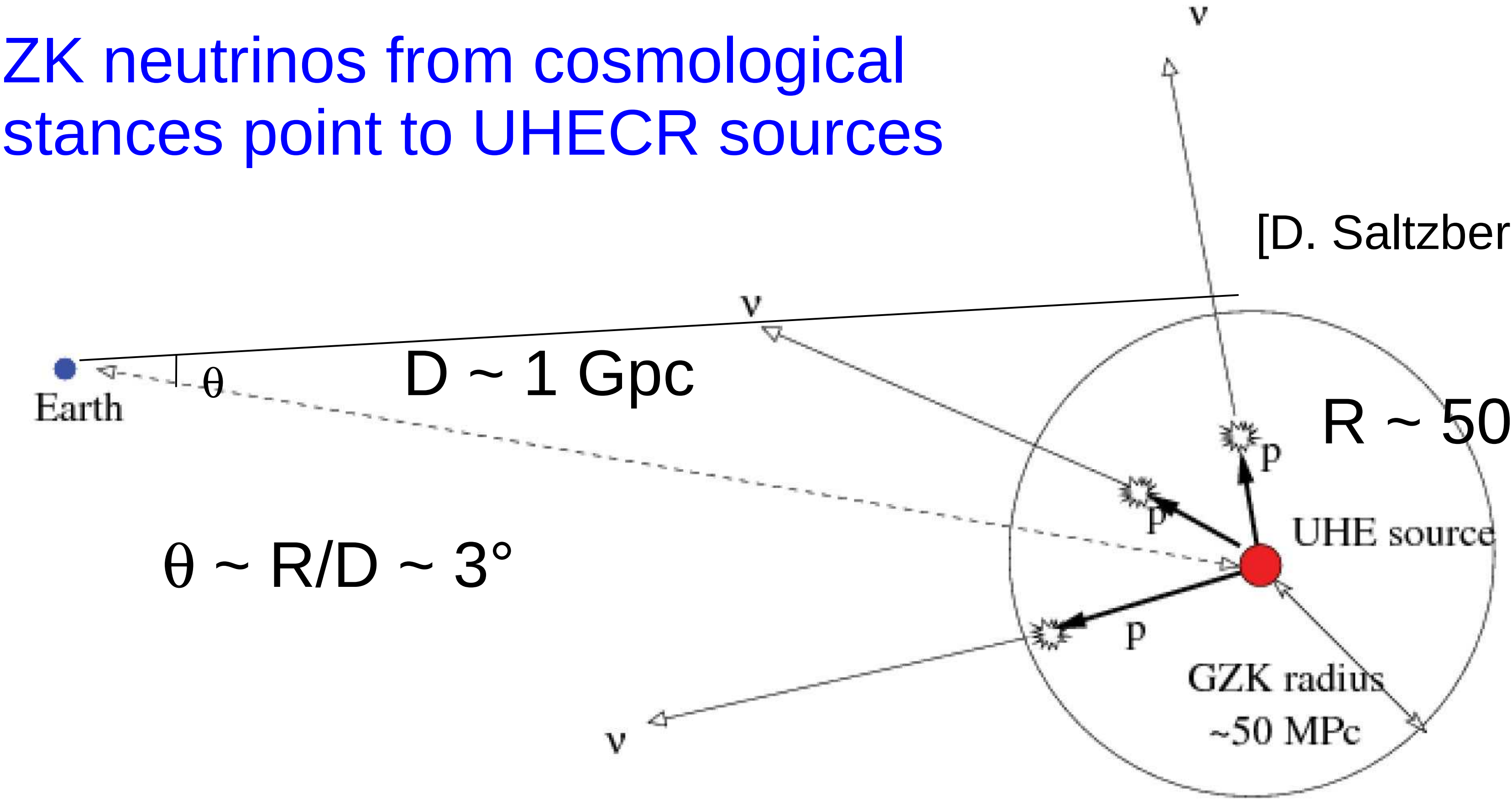




Auger 6 sigma steepening above $10^{19.7}$ eV --> GZK cutoff

GZK ν point to UHECR sources

GZK neutrinos from cosmological distances point to UHECR sources



[D. Saltzberg]

D ~ 1 Gpc

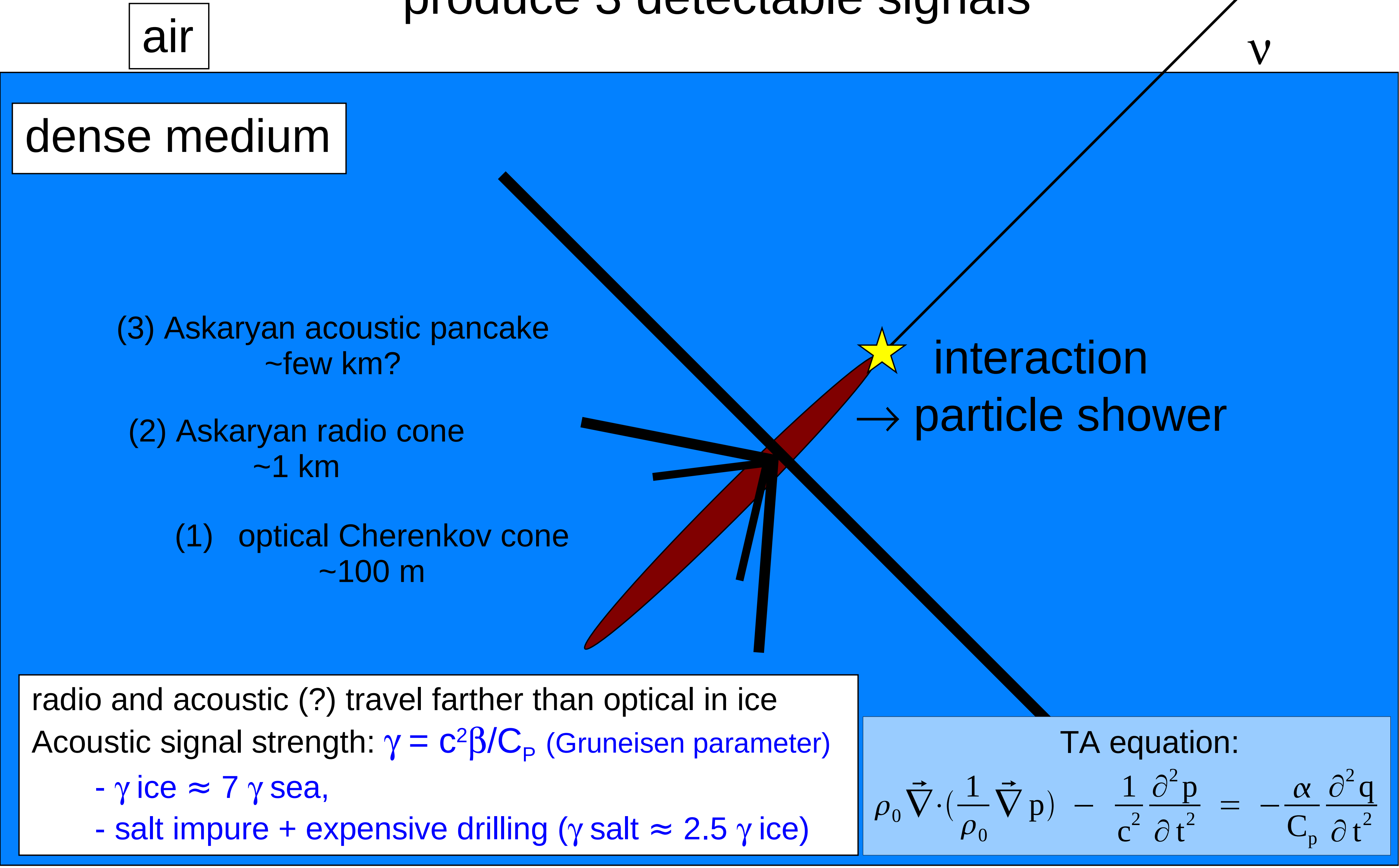
R ~ 50 Mpc

$\theta \sim R/D \sim 3°$

"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

Neutrino-induced cascades produce 3 detectable signals



air

ν

dense medium

(3) Askaryan acoustic pancake
~few km?

(2) Askaryan radio cone
~1 km

(1) optical Cherenkov cone
~100 m

interaction
→ particle shower

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

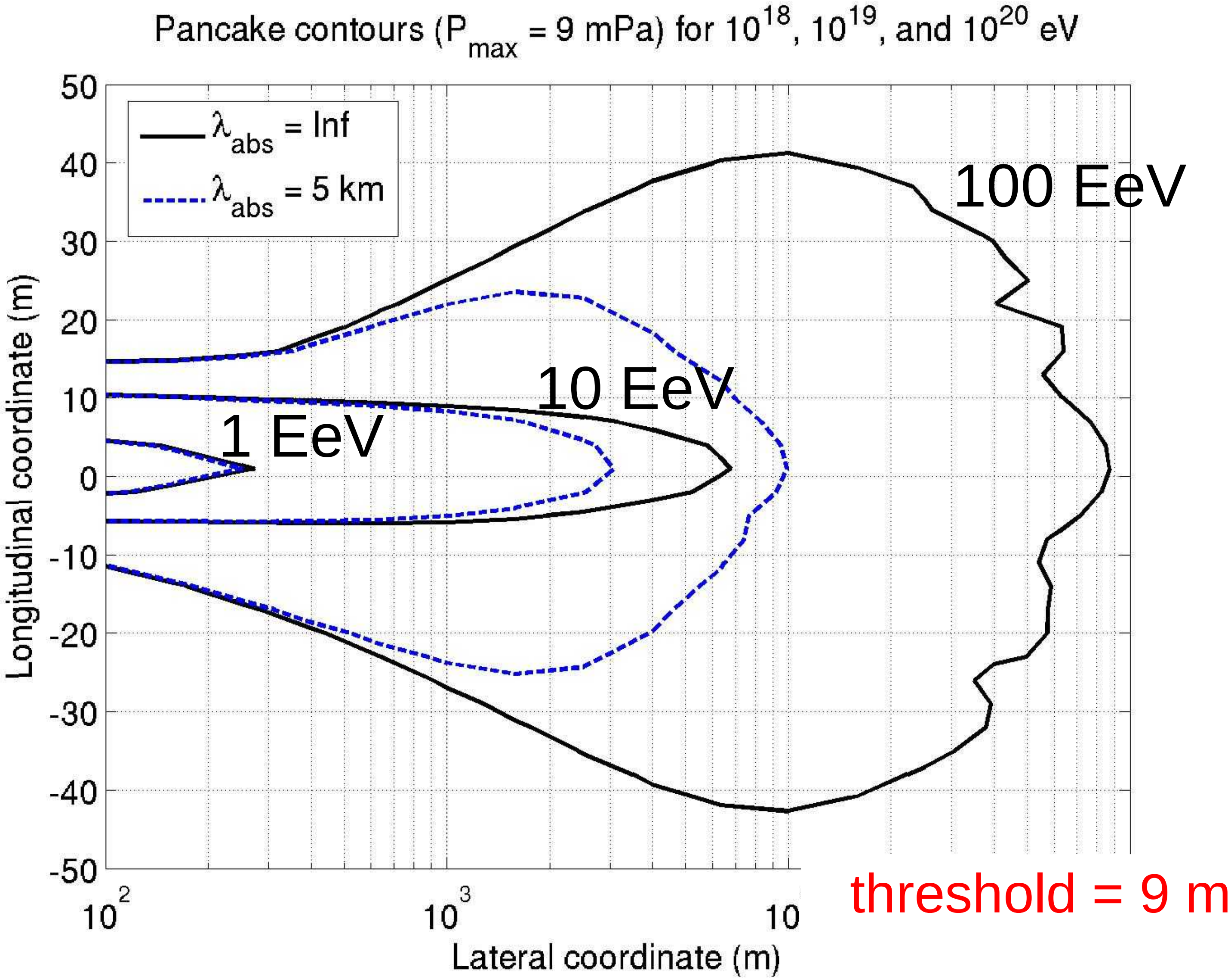
Acoustic signal strength: $\gamma = c^2\beta/C_P$ (Gruneisen parameter)

- γ ice ≈ 7 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



threshold = 9 mPa

Improving the sensor sensitivity and exploiting coincidences is very important: more channels & lower noise → e.g. With a 1 mPa threshold, we could reach 10^{18} eV with close to ~100% detection efficiency (from a 1km string spacing geometrical configuration)

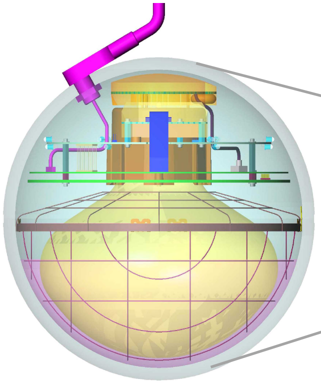
IceCube-AMANDA

-IceCube : 4800 DOMs on 80 strings

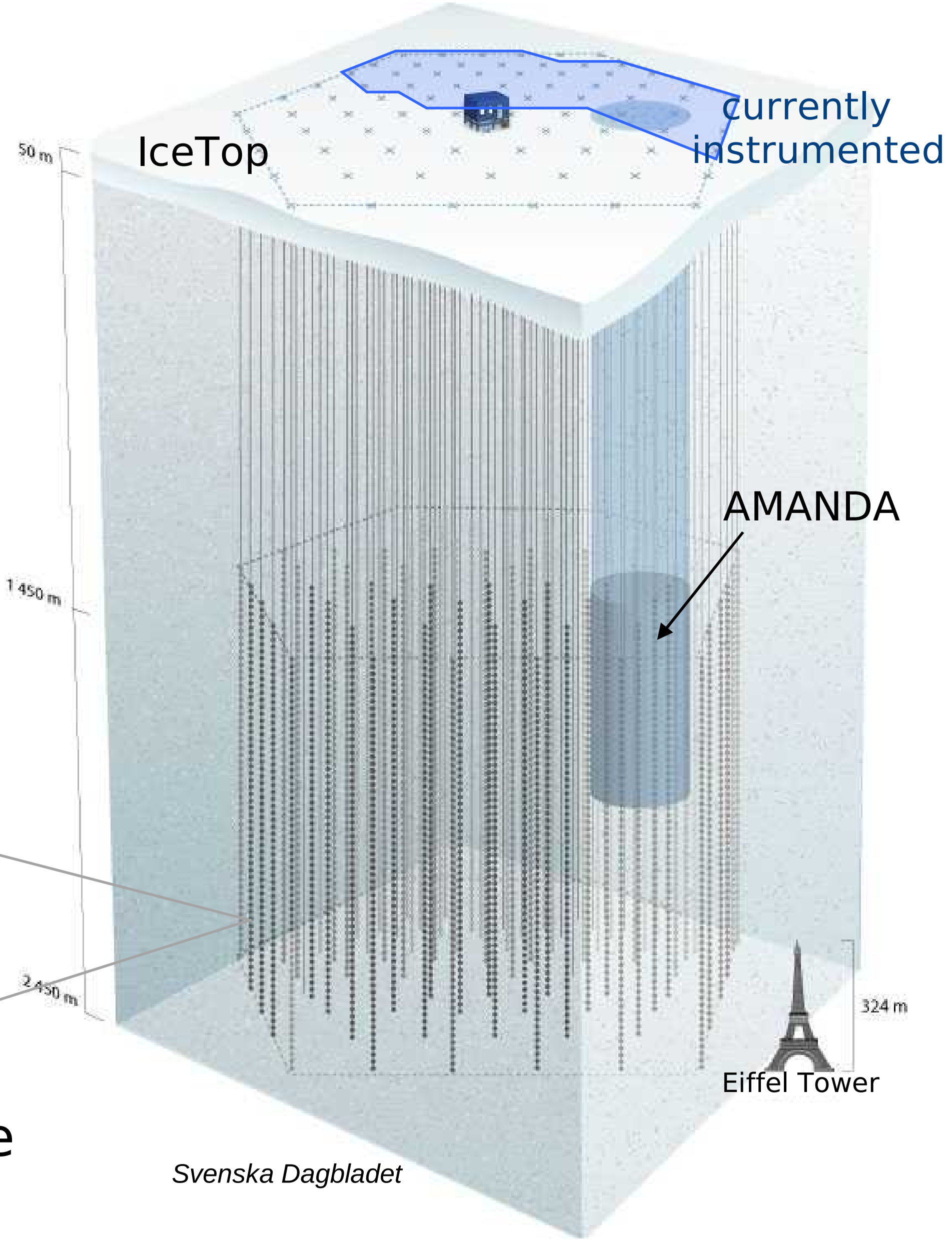
- IceTop : 160 Ice-Cherenkov tank surface

-AMANDA: 677 OMs surrounded by IceCube

January 2008: 40 of 80 strings installed !

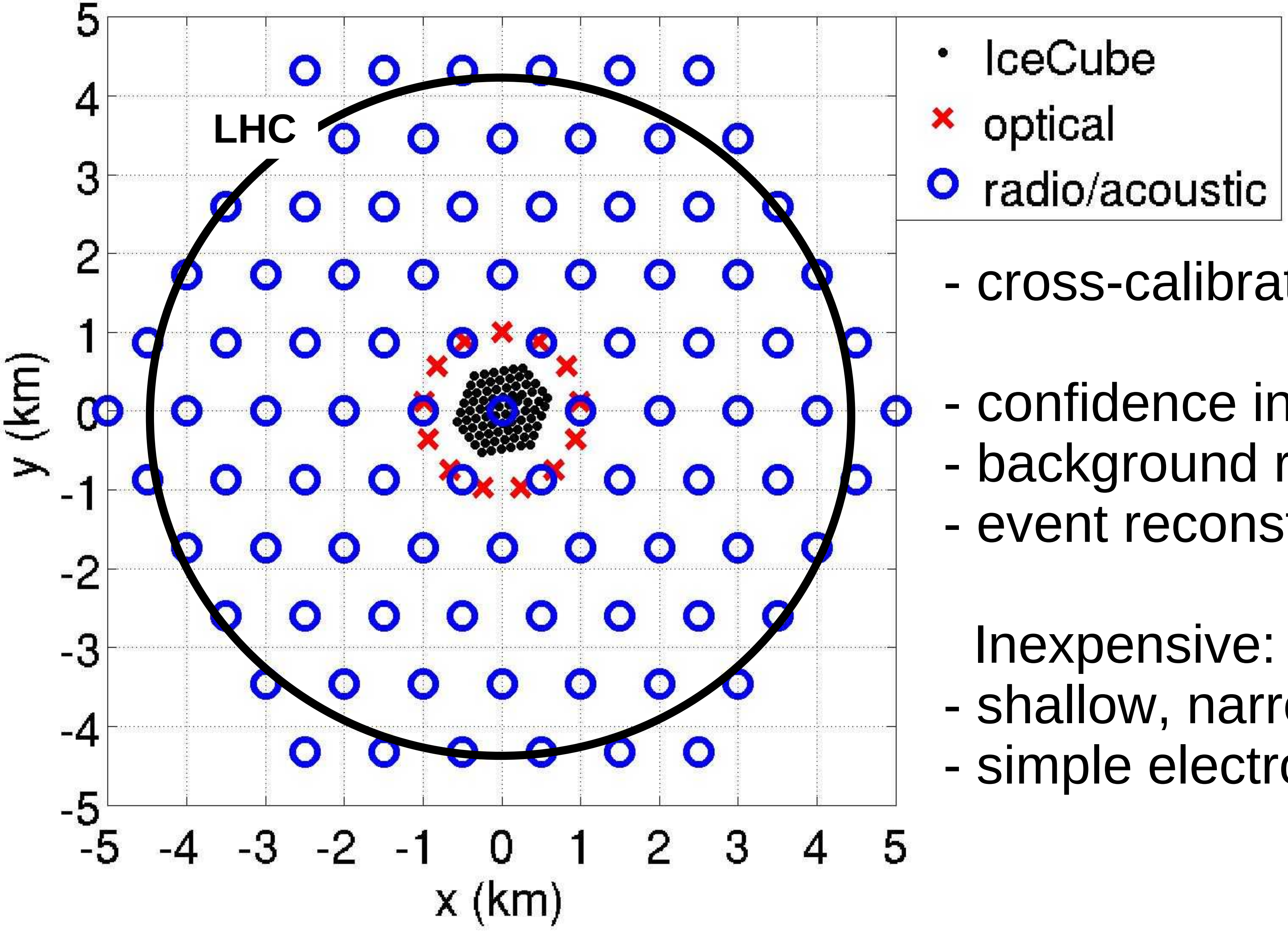


Digital Optical Module (DOM)



Svenska Dagbladet

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



- cross-calibration

- confidence in signals
- background rejection
- event reconstruction

Inexpensive:
- shallow, narrow holes
- simple electronics

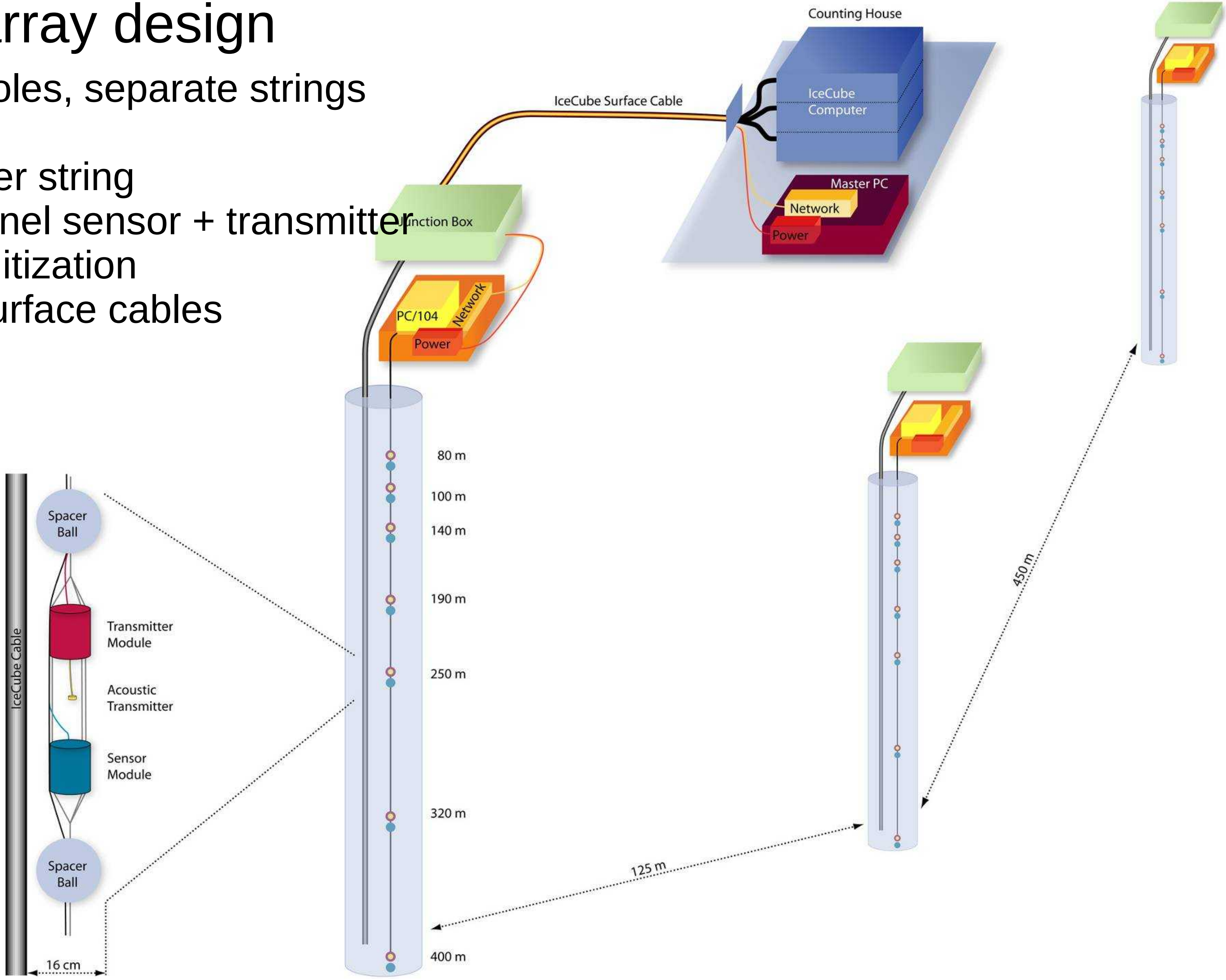
The South Pole Acoustic Test Setup (SPATS)

- First step toward large acoustic/hybrid detector at South Pole: measure ice properties in situ

- Measurement goals:
  - Attenuation
  - Noise floor
  - Sound speed vs. depth
  - Transients
    - background for us
    - interesting for glaciologists? stick/slip glacier movement or bulk ice cracking?

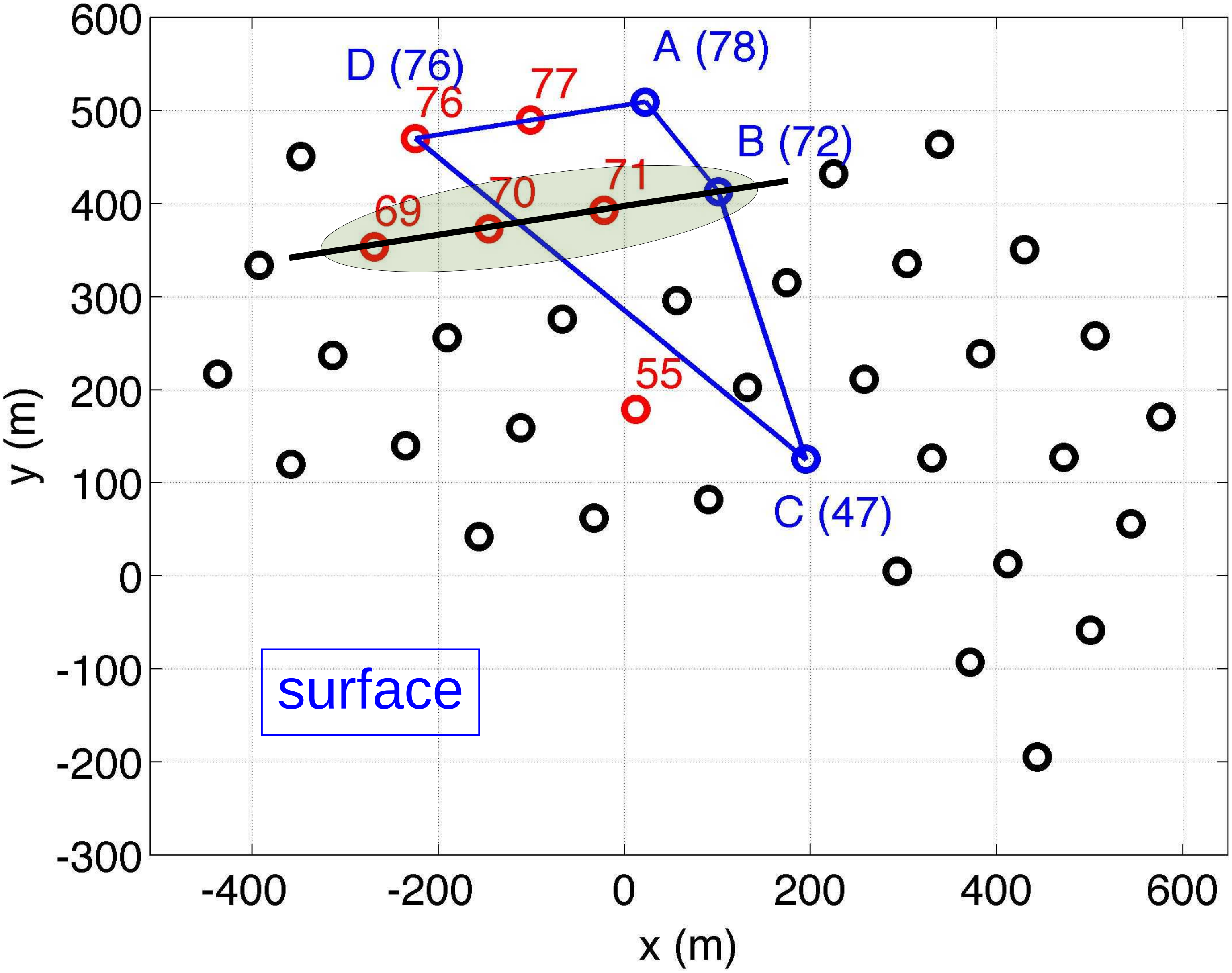
SPATS array design

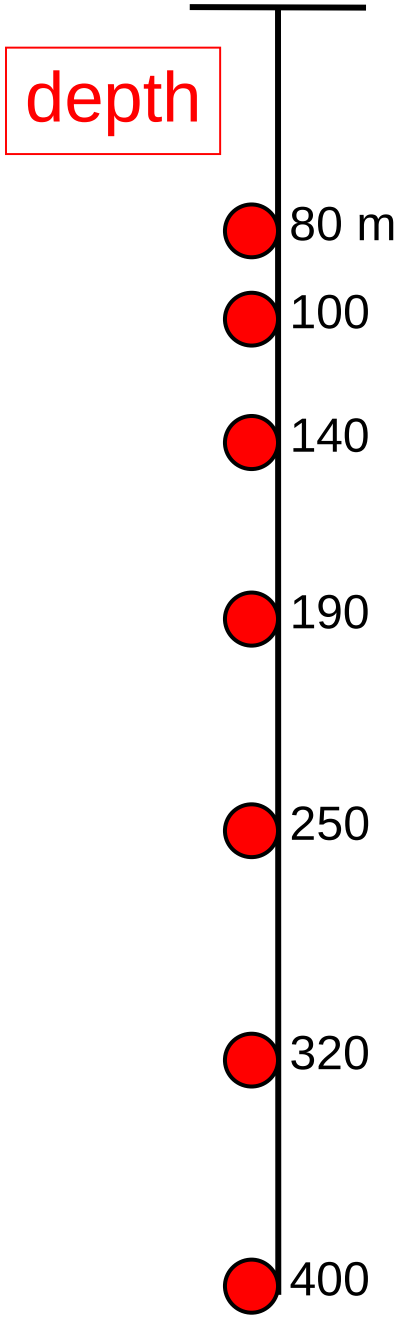
- IceCube holes, separate strings
- 4 strings
- 7 stages per string
    - 3 channel sensor + transmitter
- surface digitization
- IceCube surface cables



SPATS geometry

Data analysis in Lausanne: aligned strings 69-72





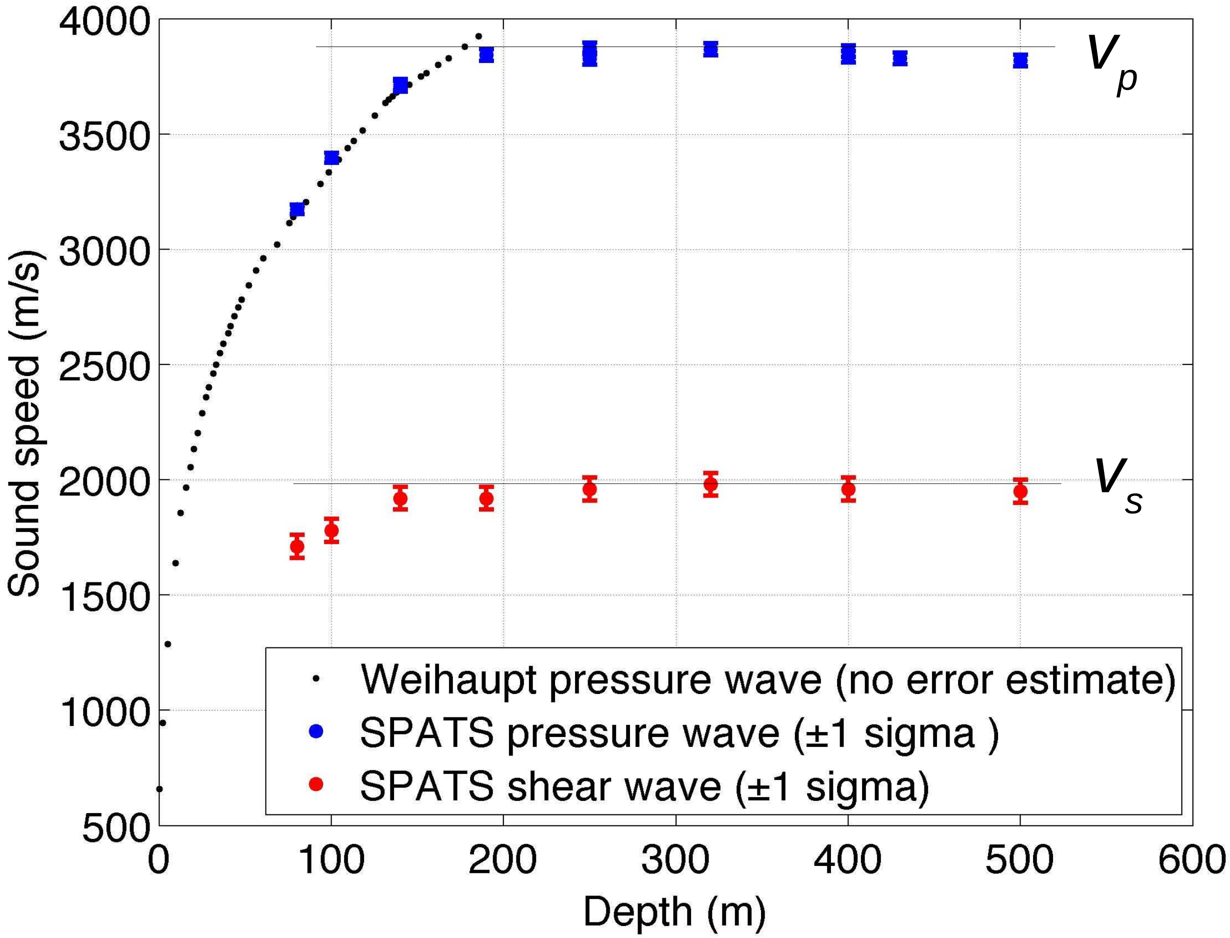
Measurement of pressure and shear wave speed vs. depth with SPATS + Pinger

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

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

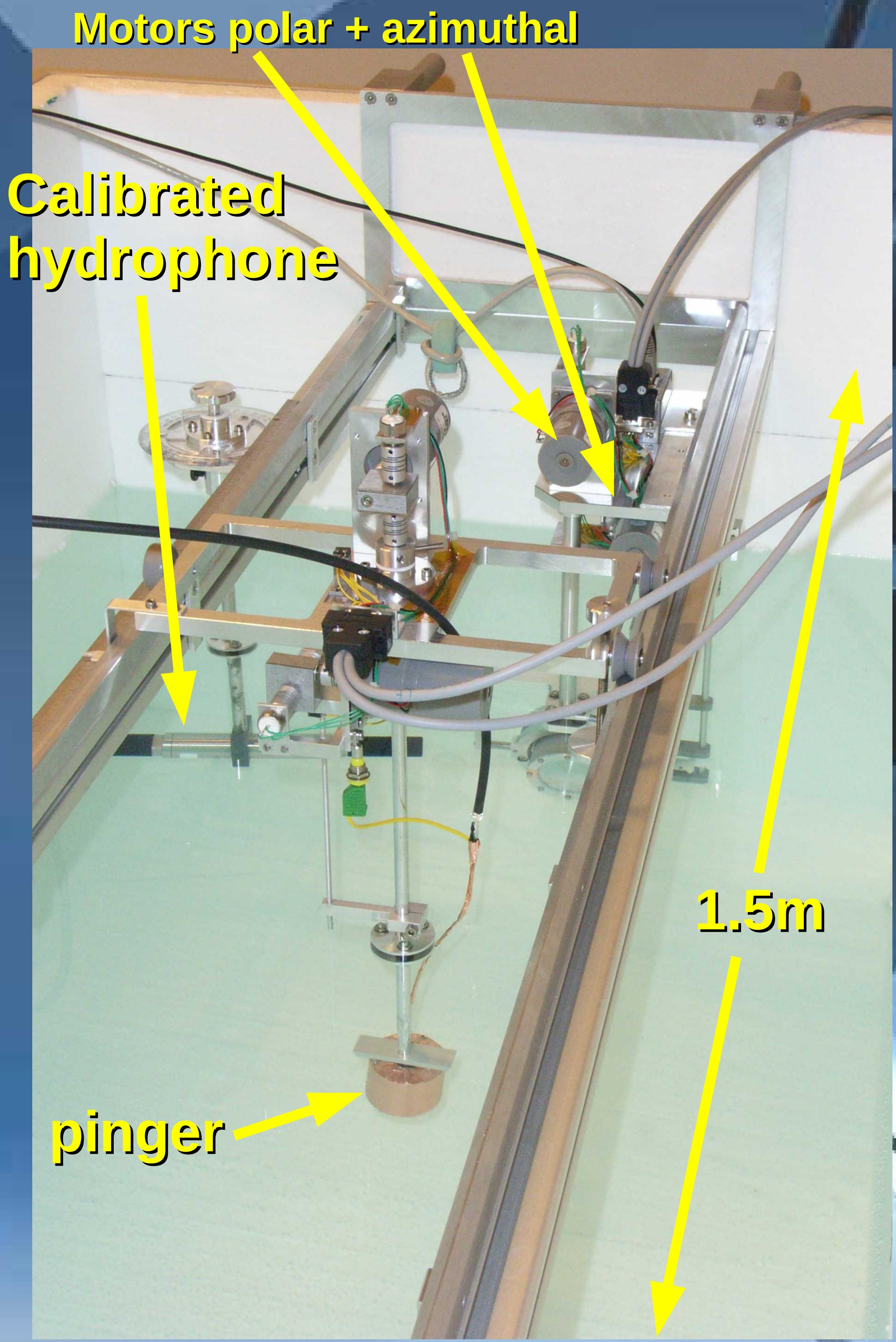
-S-wave sound speed from G (rigidity modulus)

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

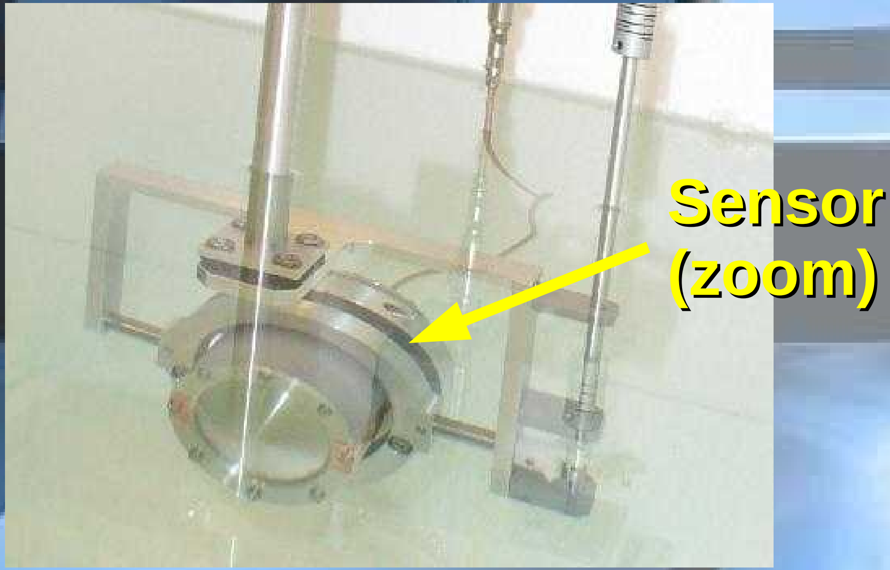


At the hole water-ice interface, P-waves are partly reflected, S-waves are generated (with amplitudes depending on the incidence angle).

Acoustic test setup at LPHE



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

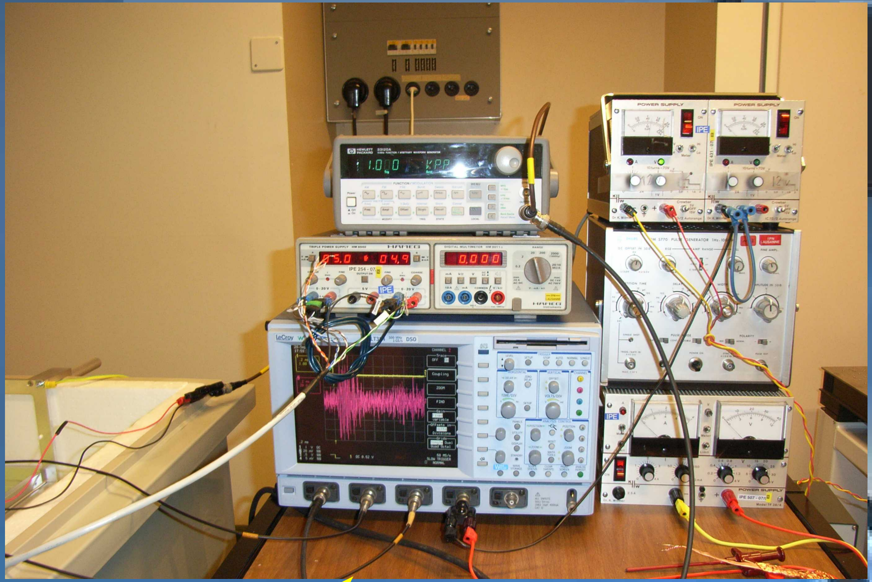


Automated relative orientation for characterization of the acoustic emission / sensing profiles

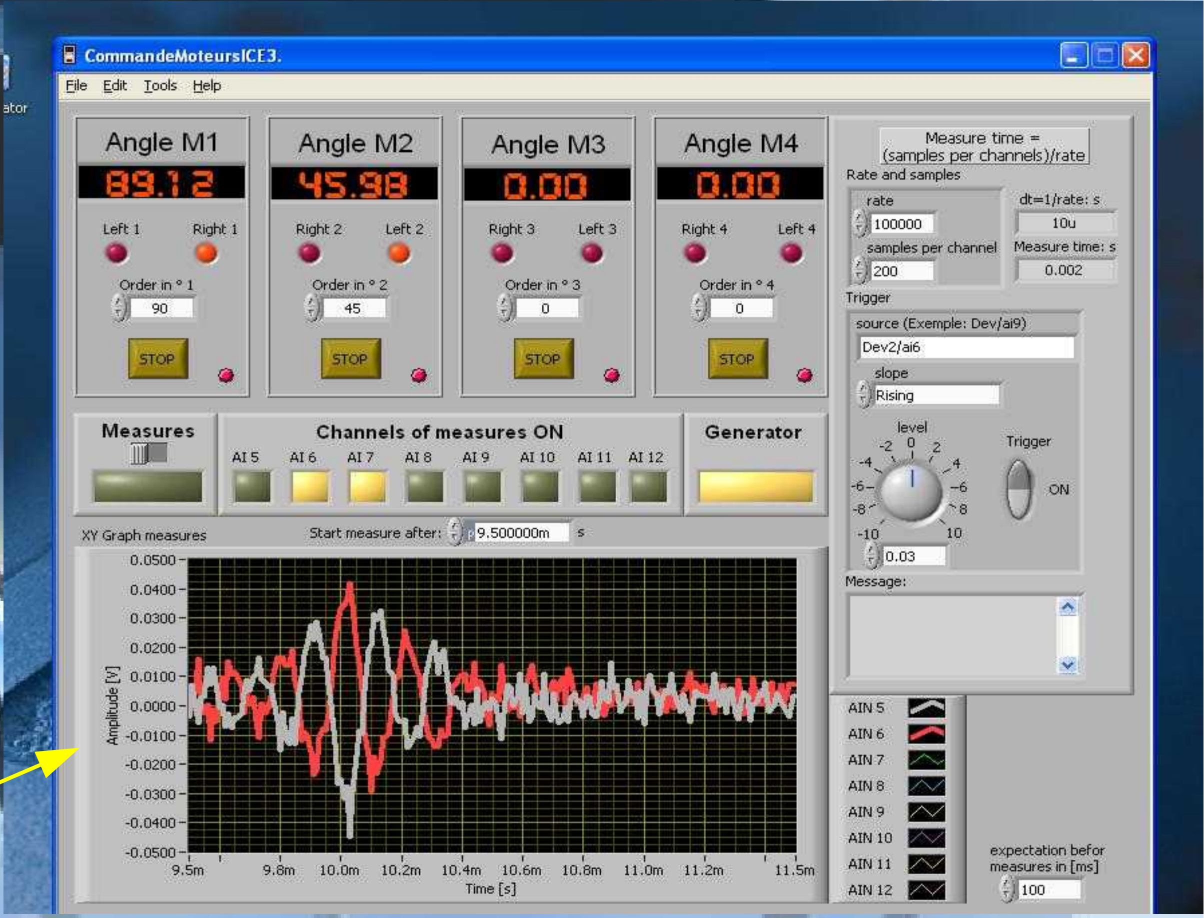
Acoustic test setup at LPHE

Nat. Instr. card interfaced (through USB) to a PC running LABVIEW:
- Relative orientation pinger – sensor (motor controlled by DACs)
- Pinger arbitrary pulse (DAC)
- DAQ for sensors (ADCs, up to a sampling frequency of 1MS/s)

--> Automatic sensor / emitter profiling



Old setup



Angle M1: 89.12
Order in ° 1: 90

Angle M2: 45.98
Order in ° 2: 45

Angle M3: 0.00
Order in ° 3: 0

Angle M4: 0.00
Order in ° 4: 0

Measure time = (samples per channels)/rate

Rate and samples
rate: 100000
samples per channel: 200
dt=1/rate: s: 10u
Measure time: s: 0.002

Trigger
source (Exemple: Dev/ai9): Dev2/ai6
slope: Rising
level: 0.03

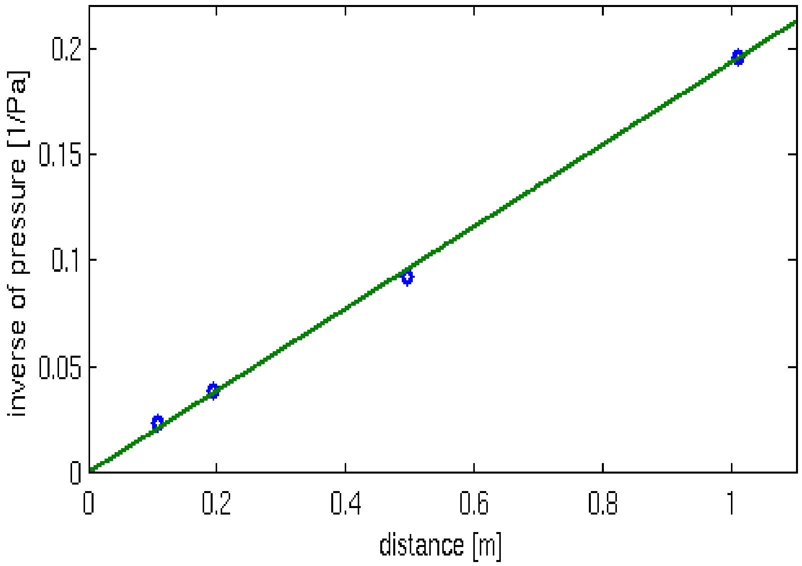
Start measure after: 9.500000m s

expectation befor measures in [ms]: 100

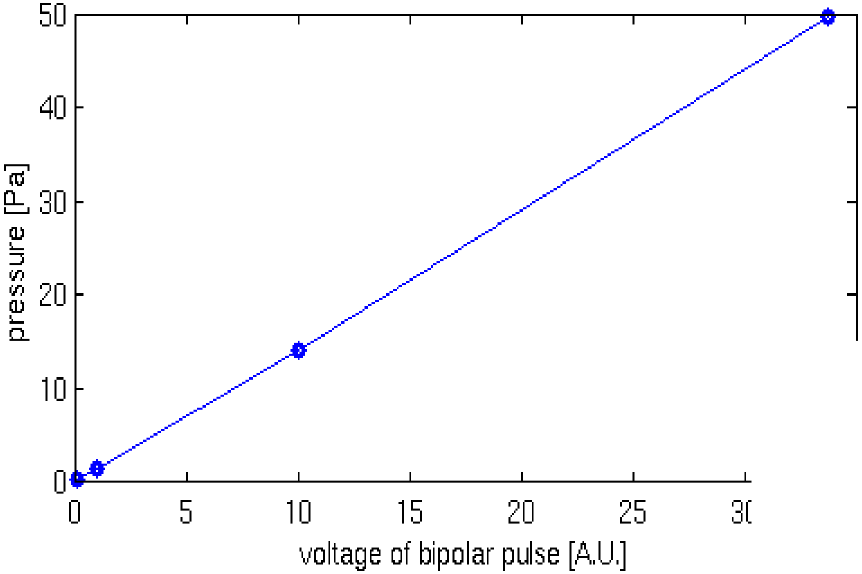
New setup

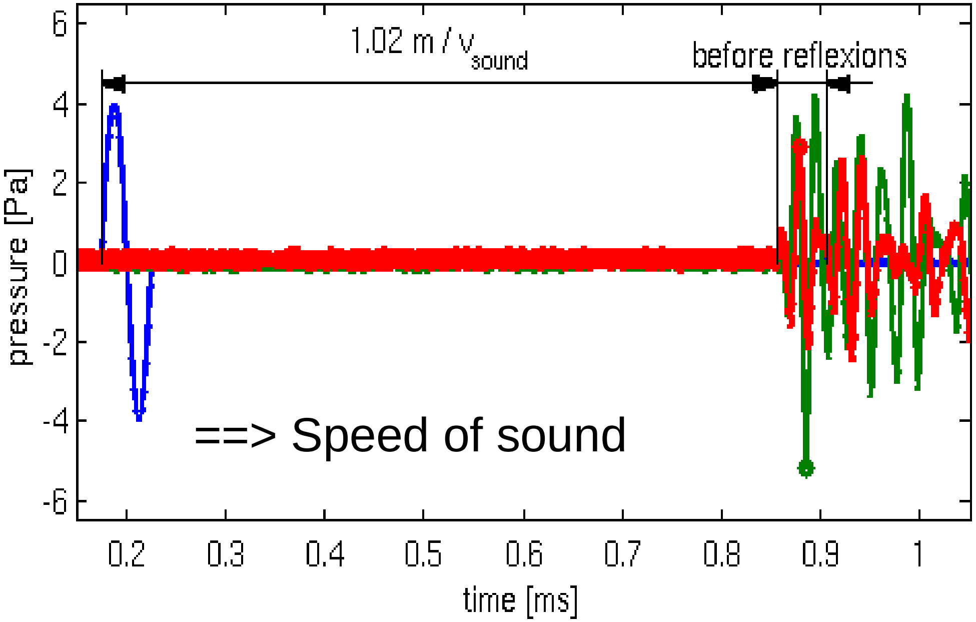
Acoustic lab test setup: 1st checks

linearity of the measured inverse pressure w.r.t. the distance sensor-emitter



linearity of the measured pressure pulse with respect to applied voltage to the emitter

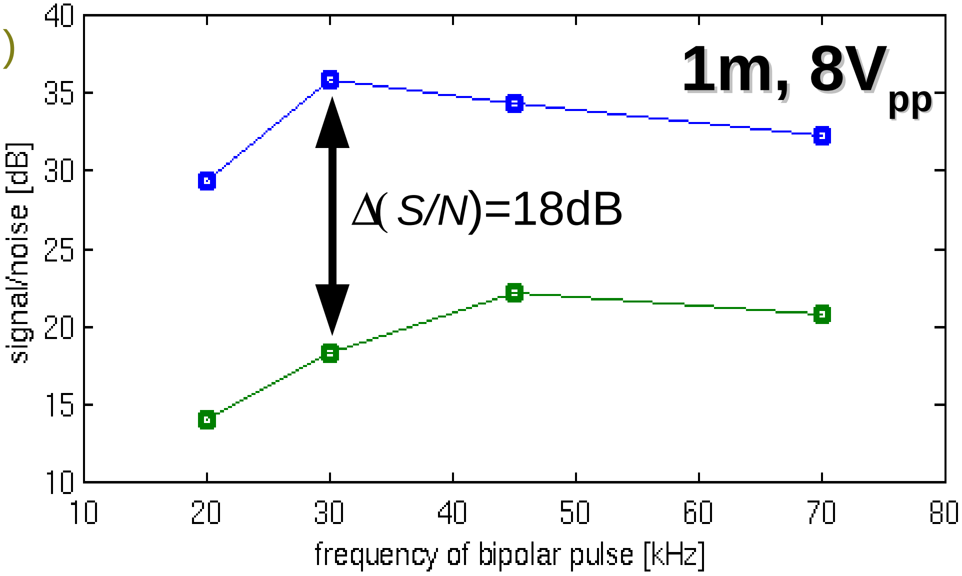




==> Speed of sound

Calibrated hydrophone SQ03 (Sensortech)

- noise level ~100 mPa (0.5 mV)
- -166 dB re V/μPa

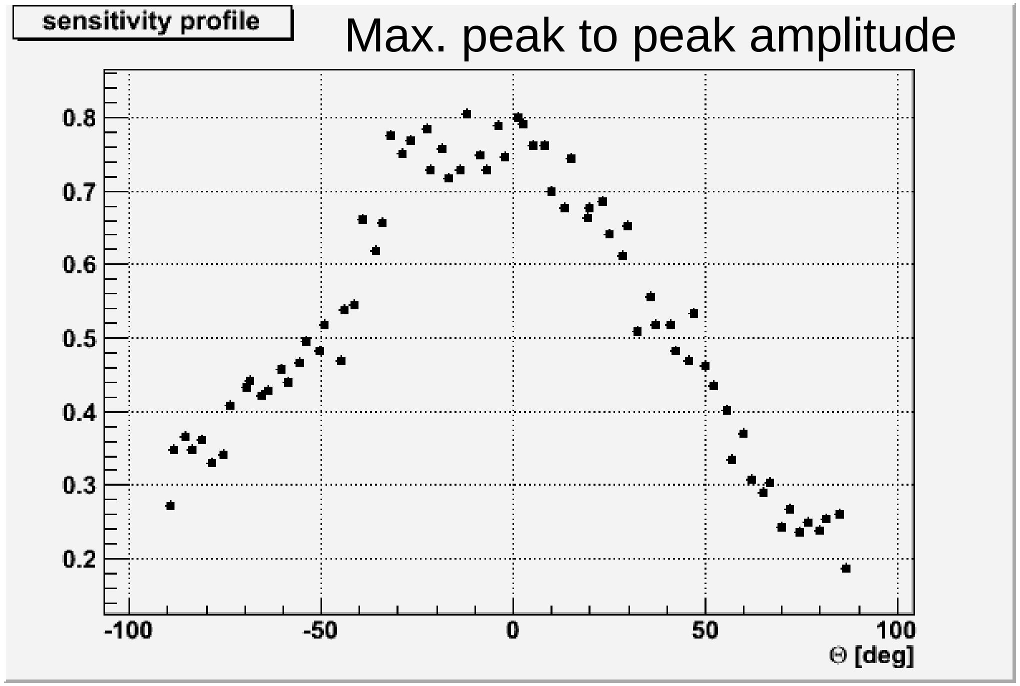


Home made sensor

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 mechanical amplifier (also transmission loss from non perfect impedance matching)



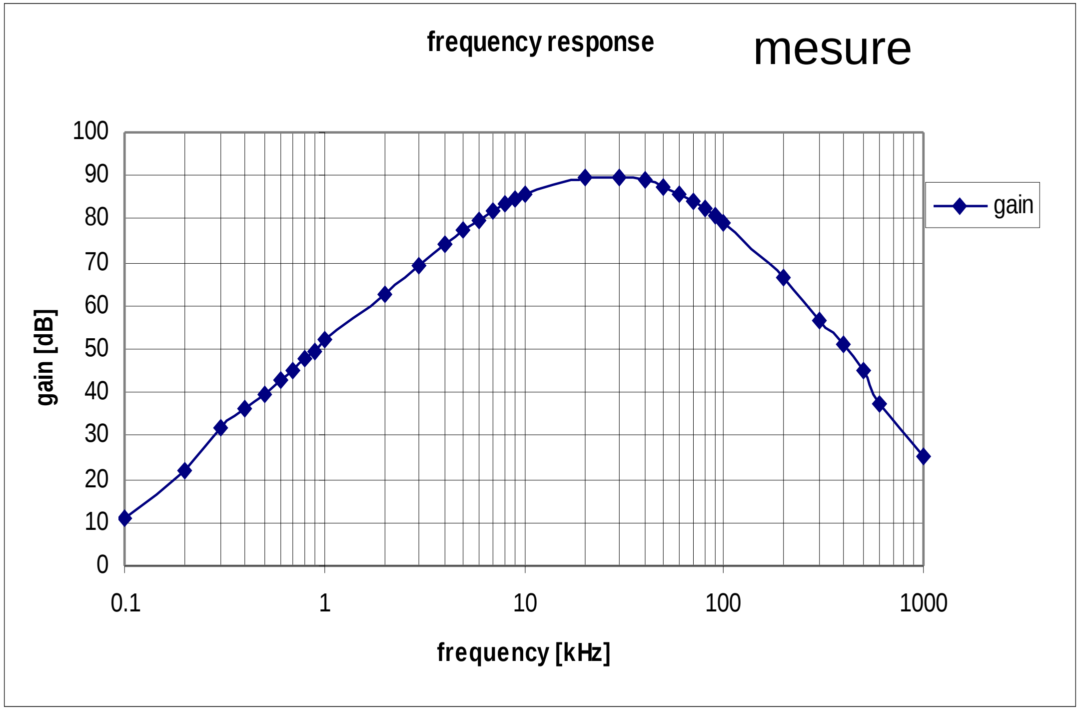
Next step is on-going

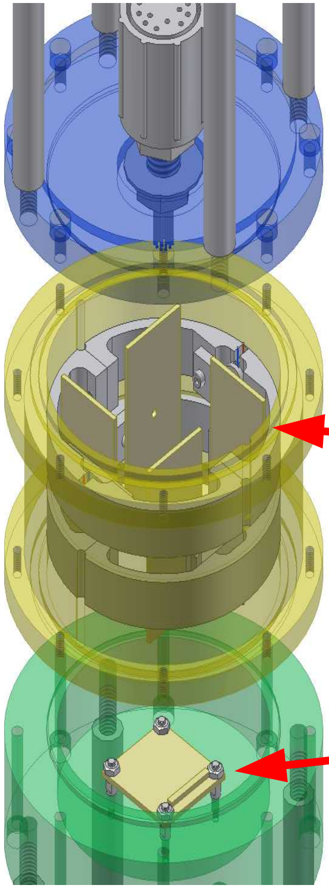
- Improving the sensor S/N by ~20 dB is necessary:
    - Reach a better noise level
    - Increase the gain
    - Adjust the gain at a given peak frequency
    - Further amelioration of the impedance matching

Electronics

- Multi-channel sensor desirable: triangulation, trigger

New design of the electronics: gain of 90 dB, peak frequency at 25 kHz with 600 nV input noise (close to what needed for mPa sensor)



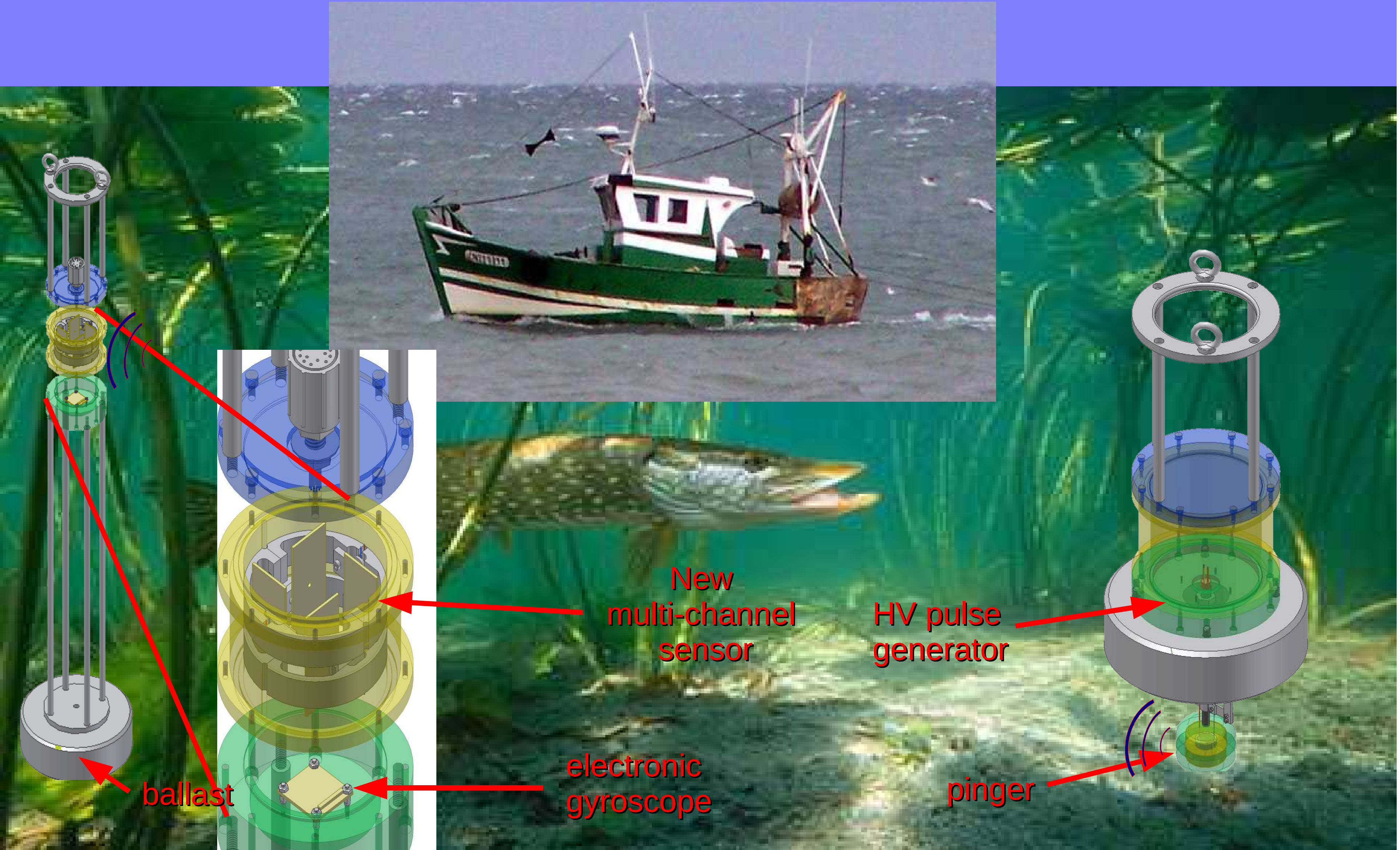


New design of a new multi-channel sensor, but without the mechanical amplifier

new multi-channel sensor

gyroscope

Soon: **On-board the ship: DAQ, wireless pulse signal**
Logistic test will hopefully take place in September at large from Lausanne midway to Evian (400m depth)



Conclusions

Fully automated water acoustic test setup operational:

- Determination of absolute sensitivity
- Emission / sensing profile of devices
- Transmitter designed at our lab was deployed at SP
- 12 mPa noise level sensor at our acoustic lab test setup

On-going activities:

- Designing improved sensor electronics with reduced noise
- Built a new multi-channel sensor (Goal: noise level below $E_\nu = 10^{18}$ eV @ 1km)
- Data analysis (Transient noise VS pressure & shear waves spectra, Working on absorption length extractions, Understanding of noise rejection, trigger, ... for future)

Future (coming month):

- Continued effort to further reduce the noise, test noise at low T
- Test in real conditions (400m depth in Geneva Lake)

The SPATS coll. will pursue its effort in order to measure the SP ice absorption length and eventually discuss of the opportunity for the deployment of a giant array (radio-)acoustic array