A multi-purpose digital acoustic sensor for the deep-sea environment

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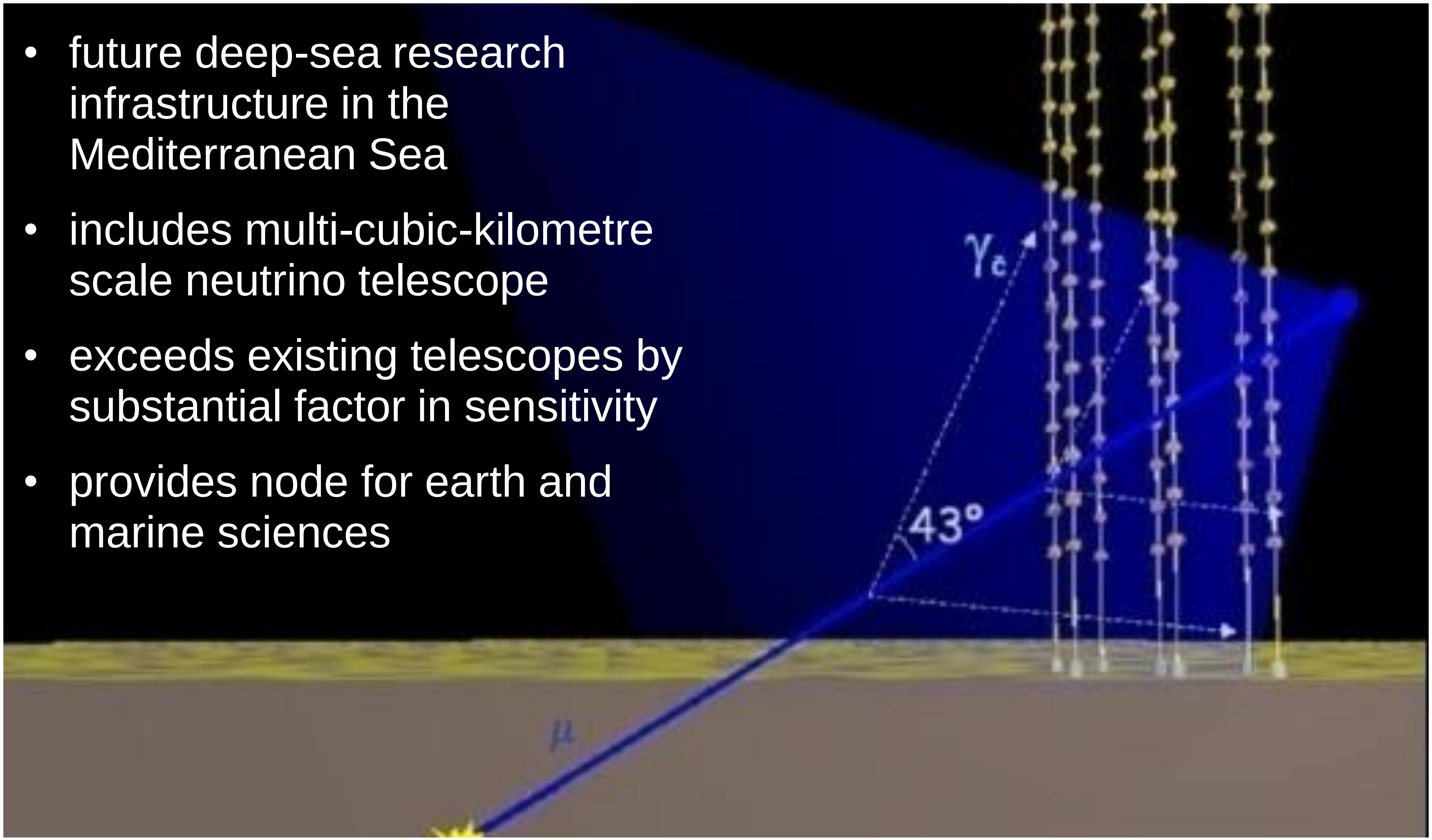
KM3NeT

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

FRIEDRICH-ALEXANDER UNIVERSITÄT ERLANGEN-NÜRNBERG

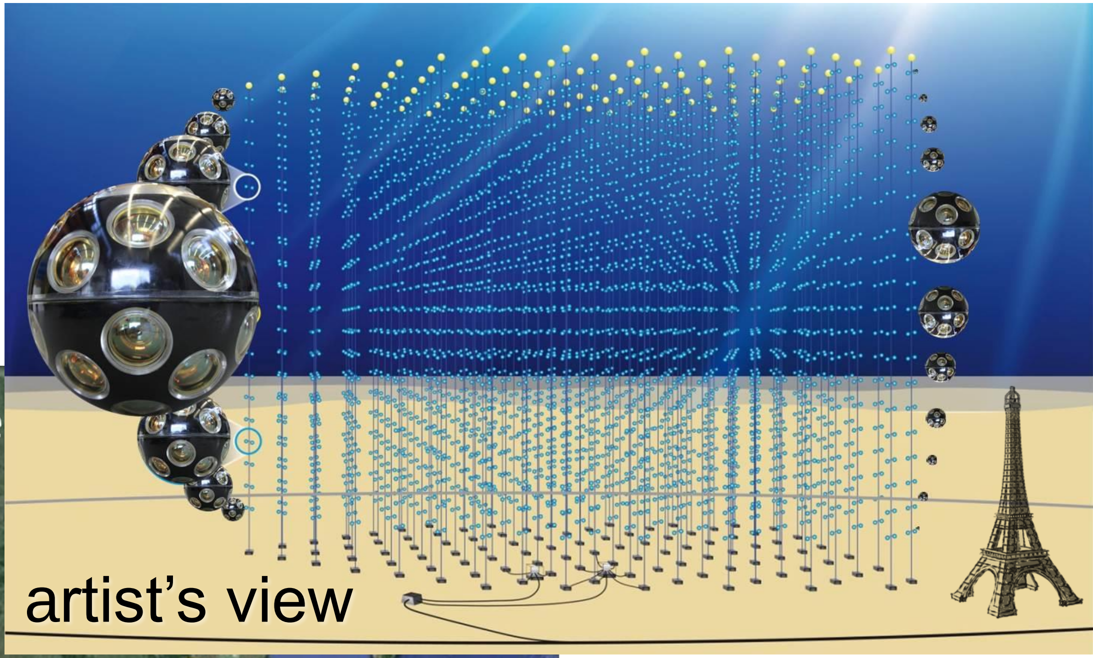
What is KM3NeT?

- future deep-sea research infrastructure in the Mediterranean Sea
- includes multi-cubic-kilometre scale neutrino telescope
- exceeds existing telescopes by substantial factor in sensitivity
- provides node for earth and marine sciences



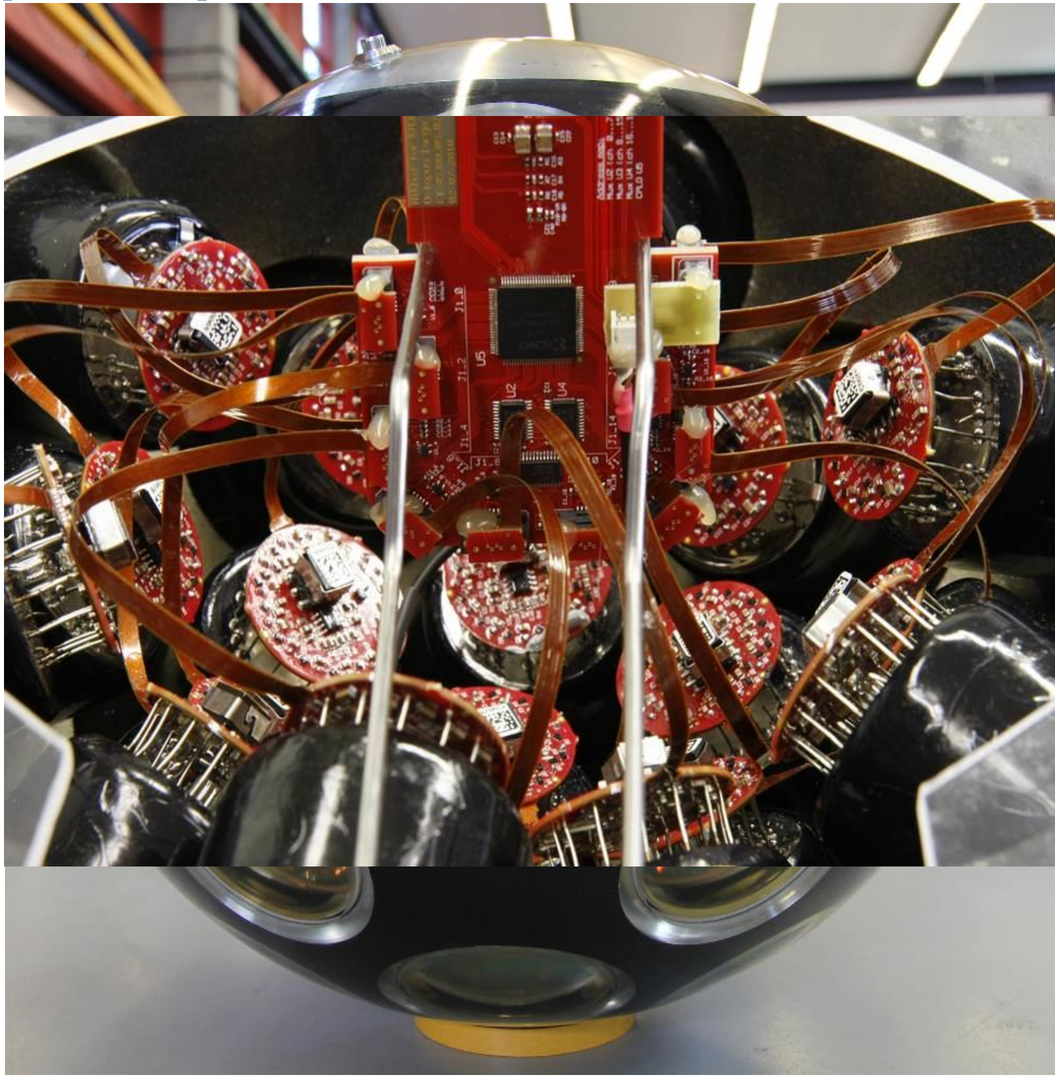
KM3NeT: Detector and Collaboration

- 38 institutes
- 3 installation sites
- starting installation of first phase



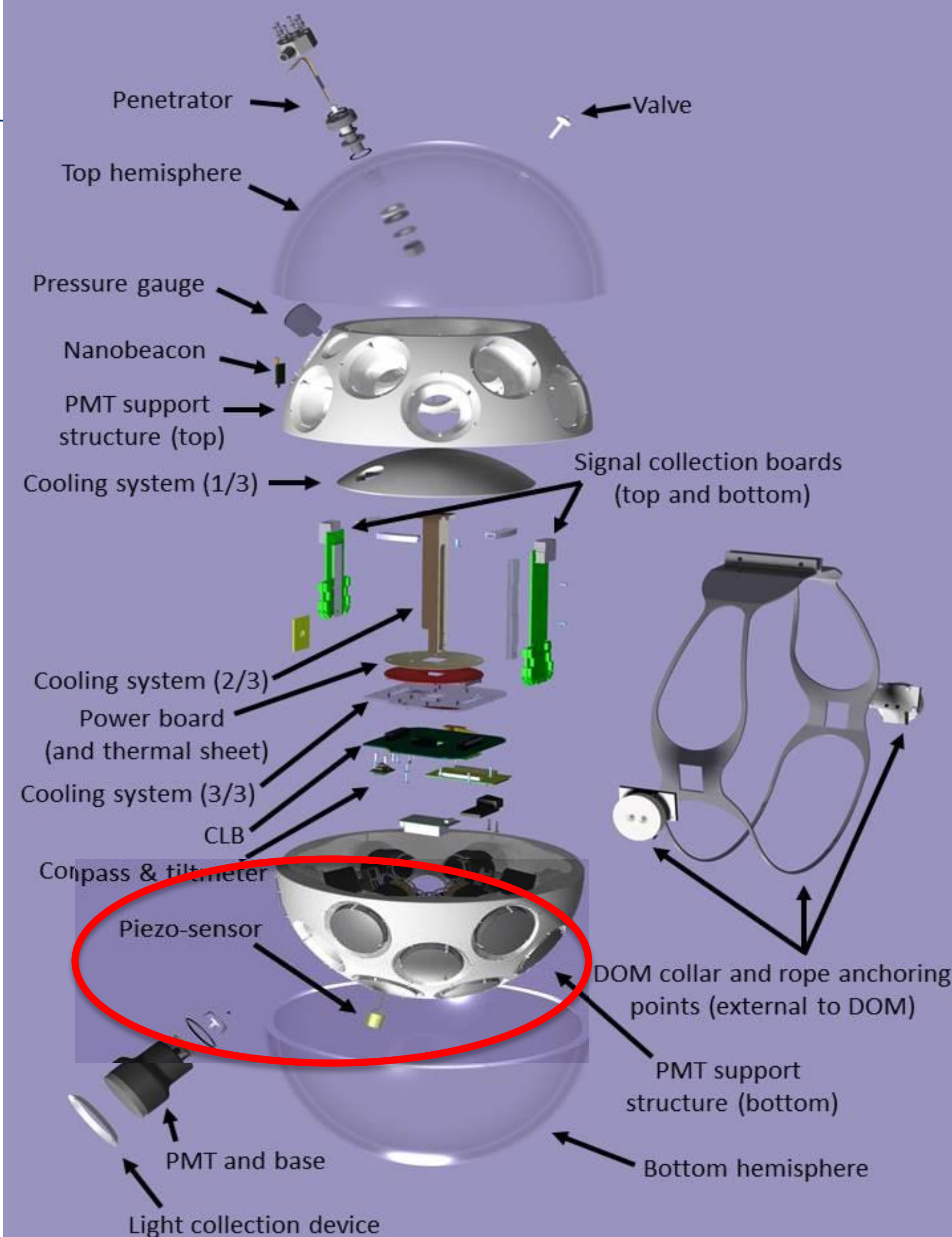
Digital Optical Modules (DOMs)

- glass sphere (⌀ 43 cm)
- 31 3-inch photomultipliers (PMTs)
- electronics
  - FPGA-based DAQ
  - “all-data-to-shore”
  - digitisation (“time over threshold”)
  - data transfer via SFP transceivers
  - additional instrumentation
    - **acoustic sensor**
    - compass and tiltmeter (AHRS)
    - optical emitters
    - environment sensors



DOM Specifications

- pressure and corrosion resistant
  (sea water up to 4 km depth)
- stable operation for 10+ years
- low power (<10W)
- compact design
- minimal "external" components



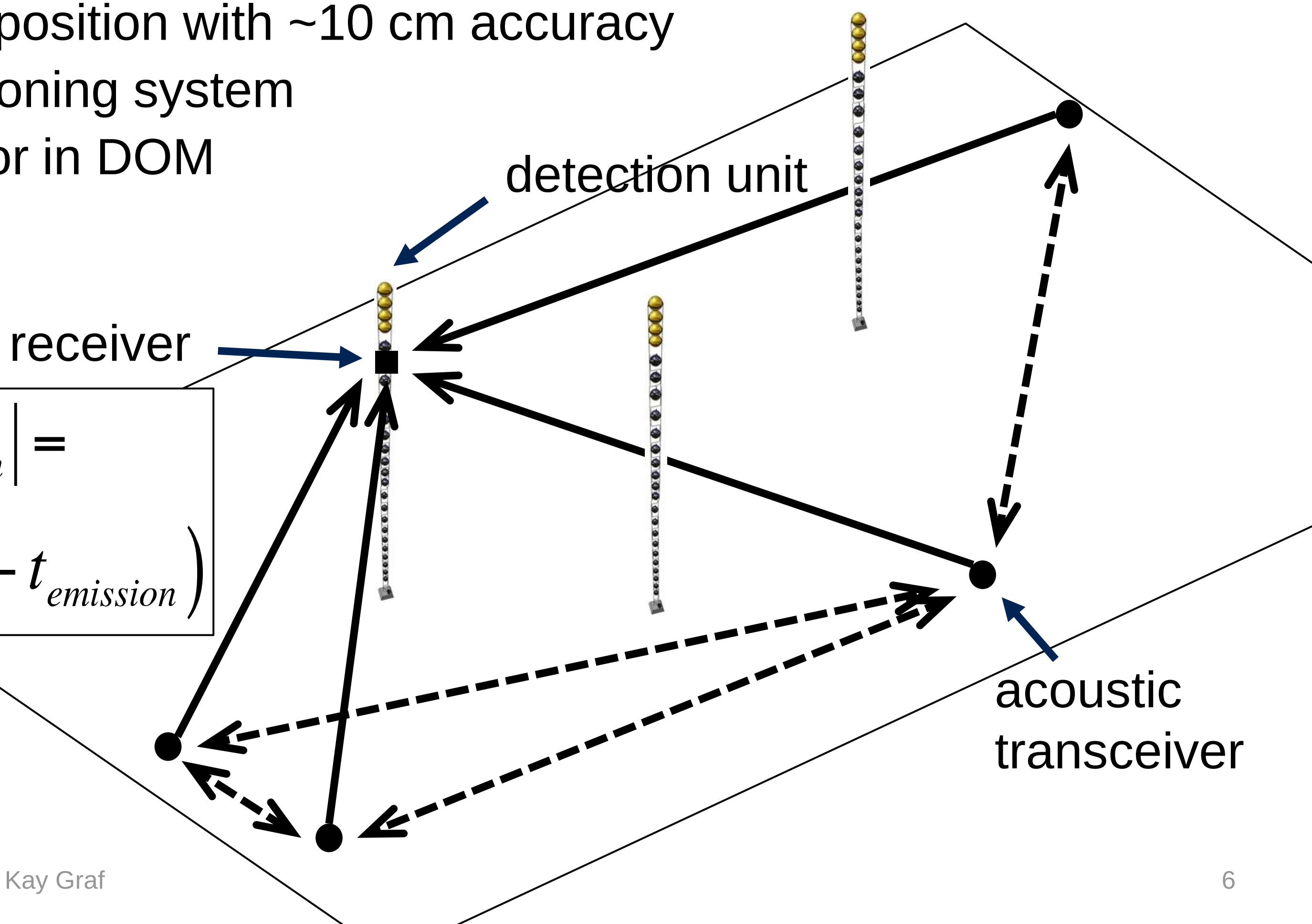
Acoustic Positioning System

- detection units not rigid, bending in sea current
- monitoring of position with ~10 cm accuracy

⇒ acoustic positioning system

⇒ acoustic sensor in DOM

$$\left|\vec{r}_{reception} - \vec{r}_{emission}\right| =$$
$$= c_S \times \left(t_{reception} - t_{emission}\right)$$

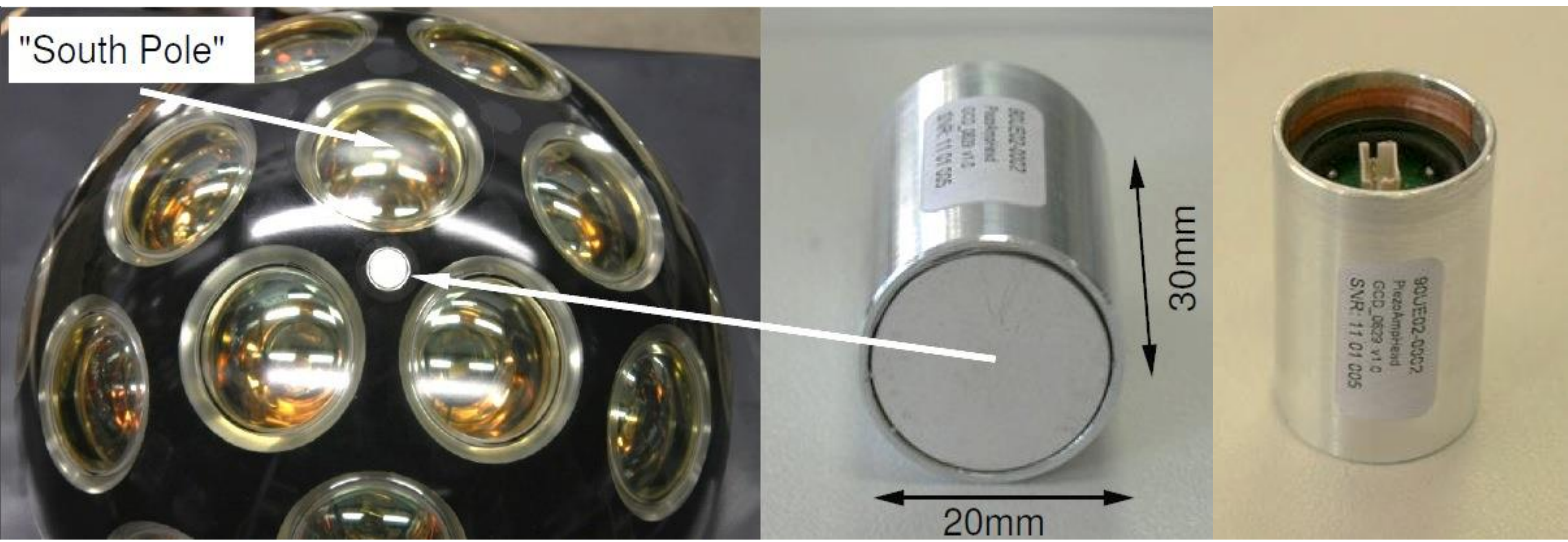


Basic Concept

Integration of acoustic sensor(s) in DOMs

⇒ compact, low-cost integrated acoustic sensors needed

⇒ main challenge: electromagnetic interference from photomultipliers

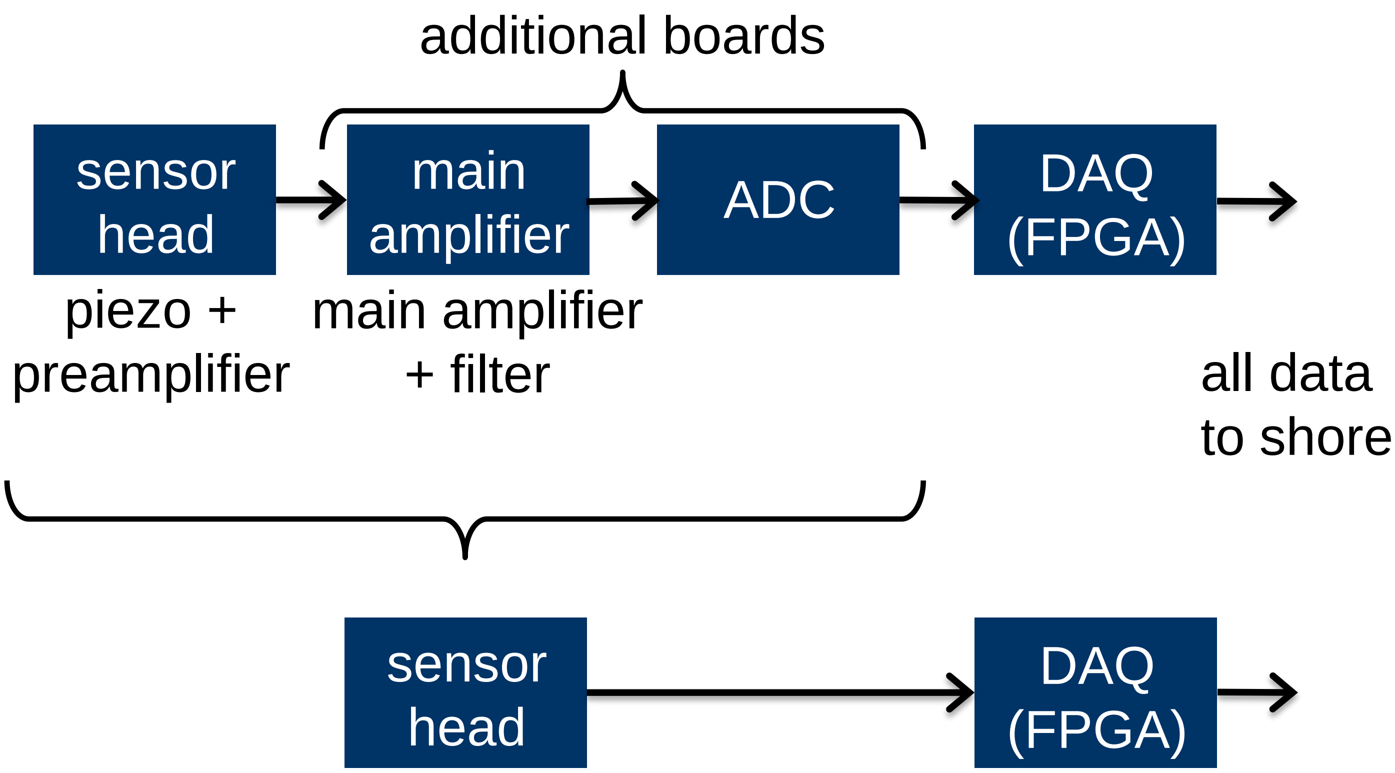


Reference: www.km3net.org

Acoustic Sensor Design Steps

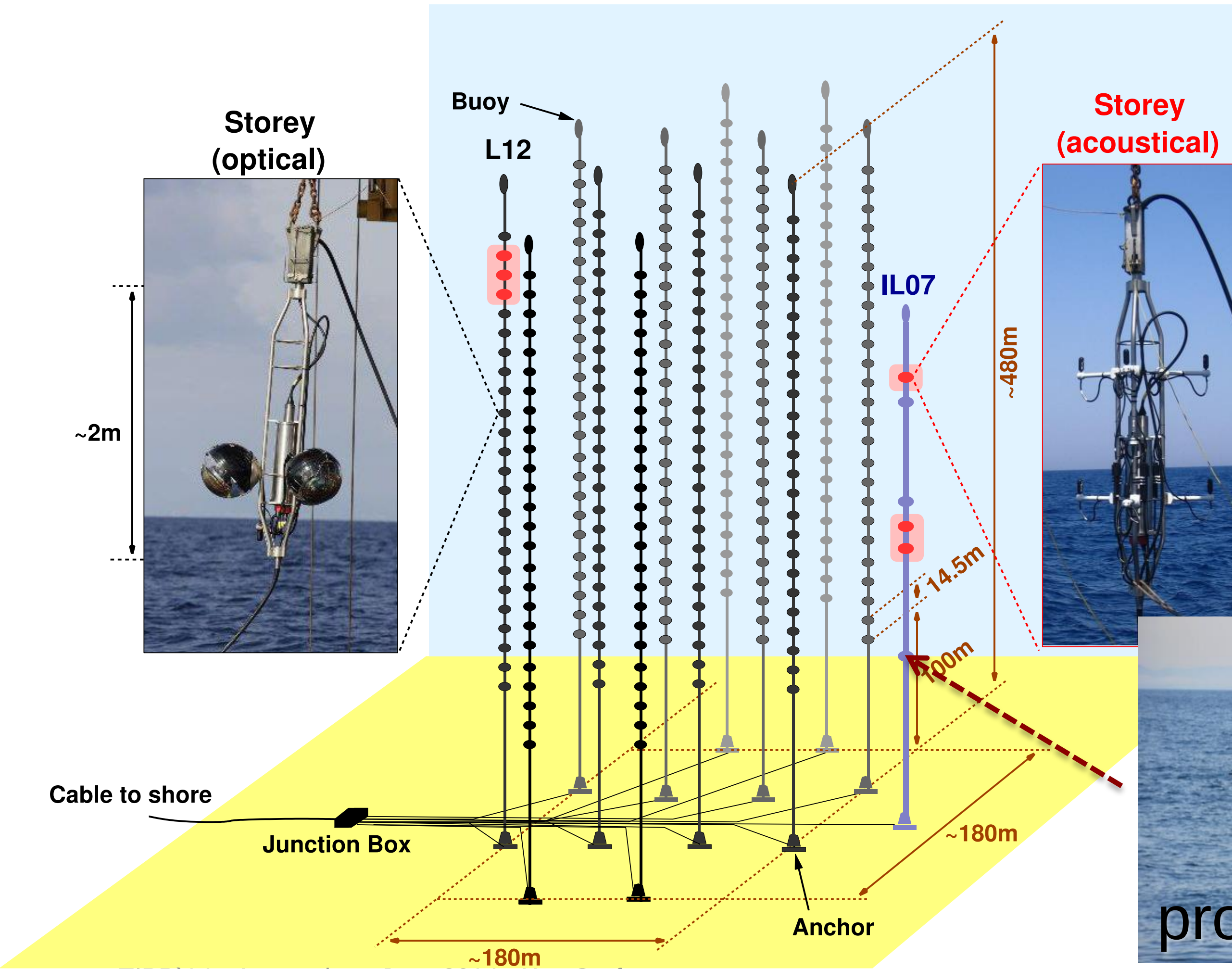
prototype:
analogue
sensor

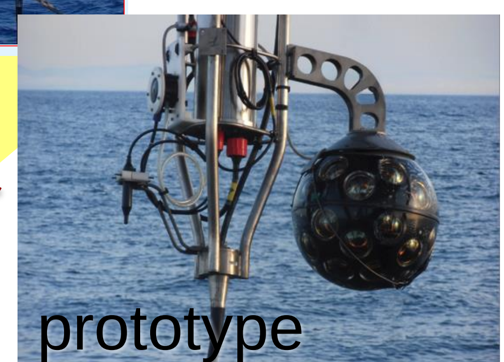
final design for
KM3NeT:
digital sensor



⇒ on shore: data processing in computer farm
(filtering, time of arrival, position calculation)

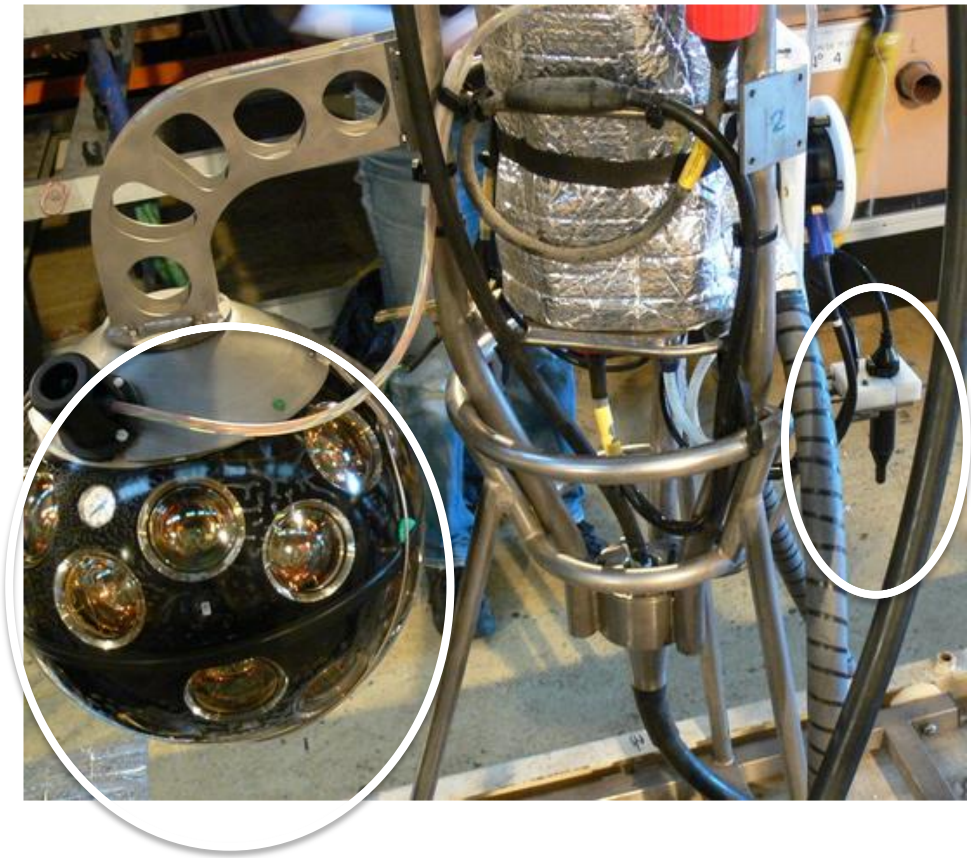
ANTARES Detector





Prototype Tests in ANTARES

DOM including analogue sensor



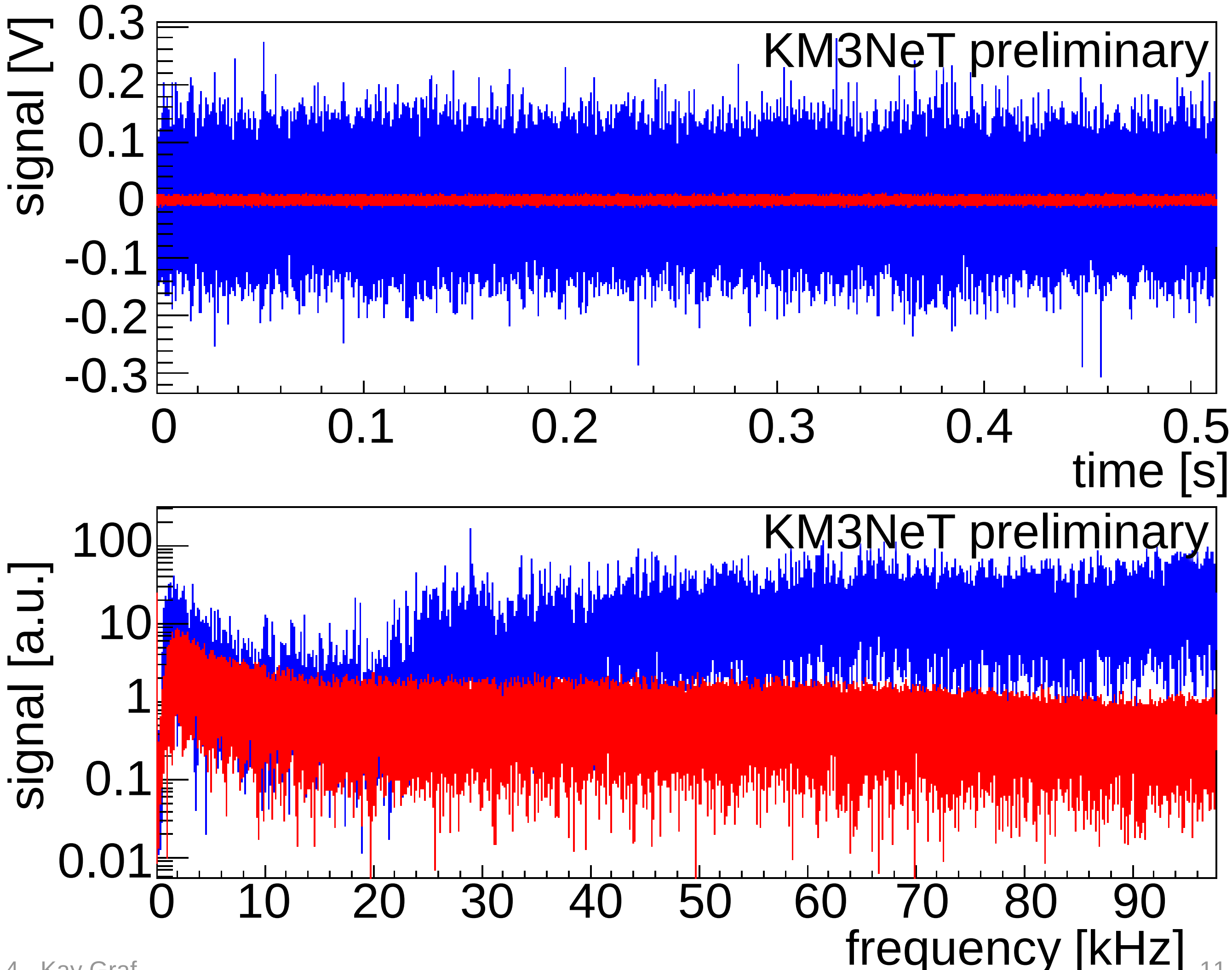
hydrophone:
- proven technology
- various devices available

⇒ comparable performance for position calibration

Laboratory Measurements

PMTs off
PMTs on

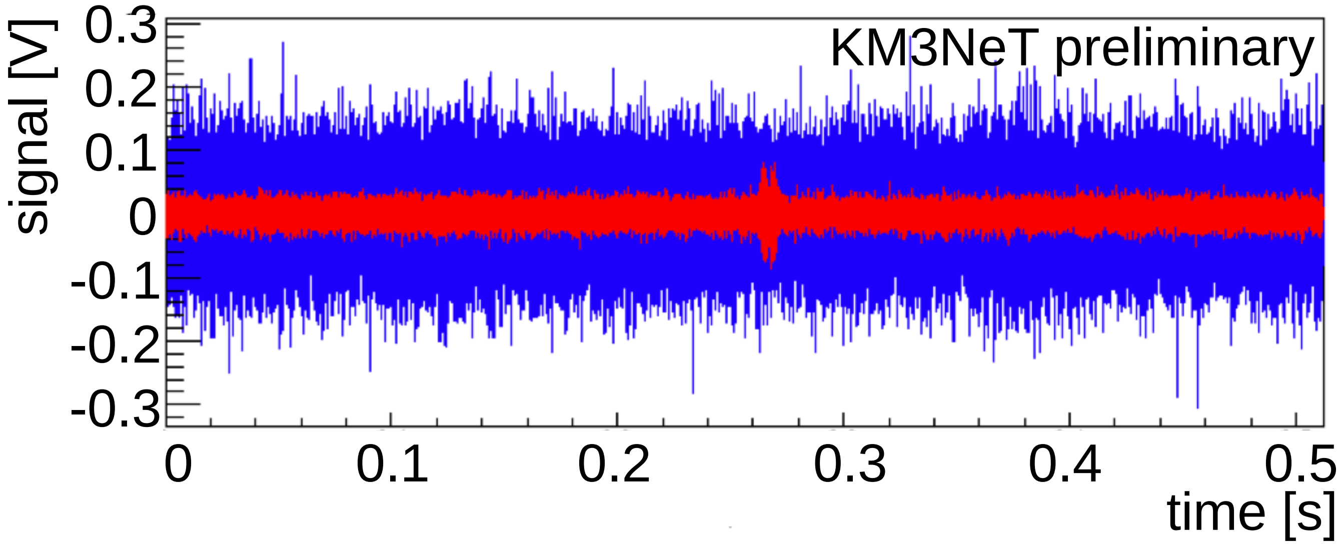
operation of PMTs injects noise into system

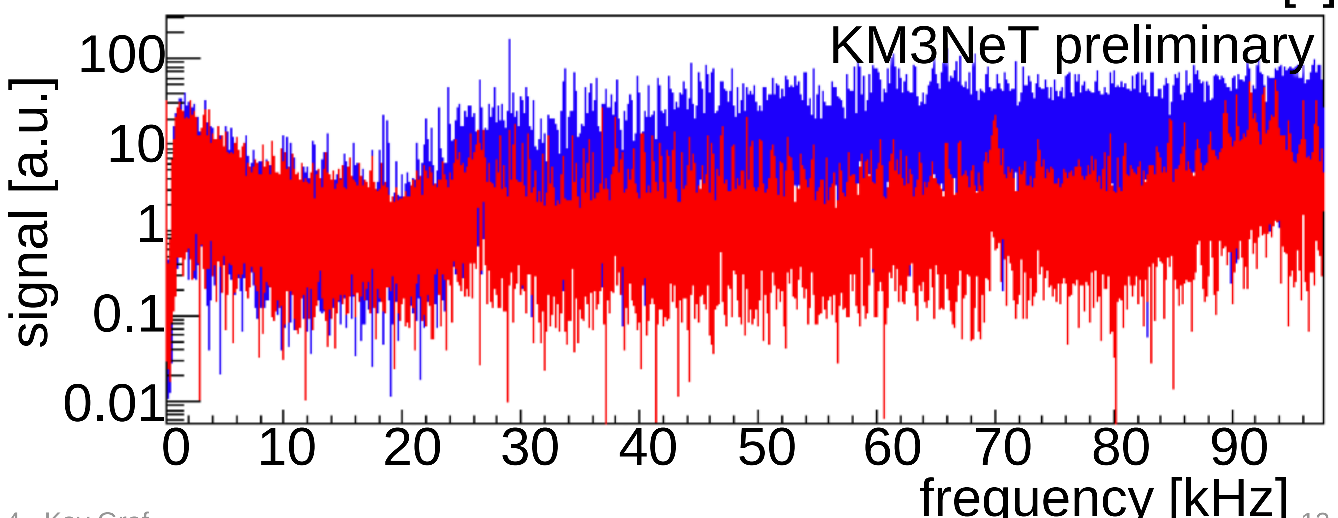


Comparison: Performance in Lab and Sea

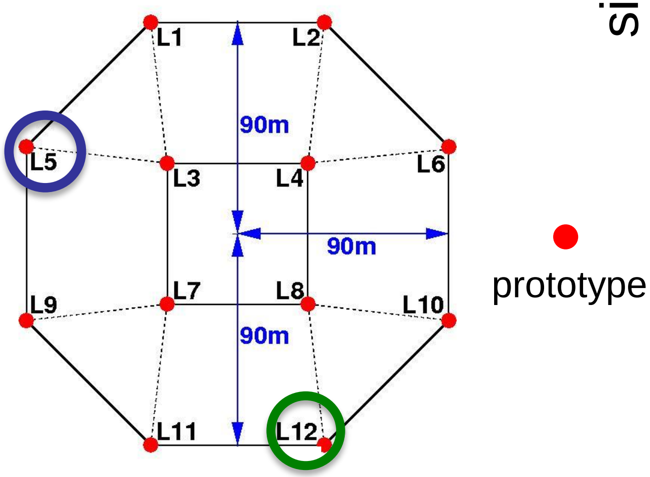
PMTs on:
Sea
Lab

less noise
in the sea

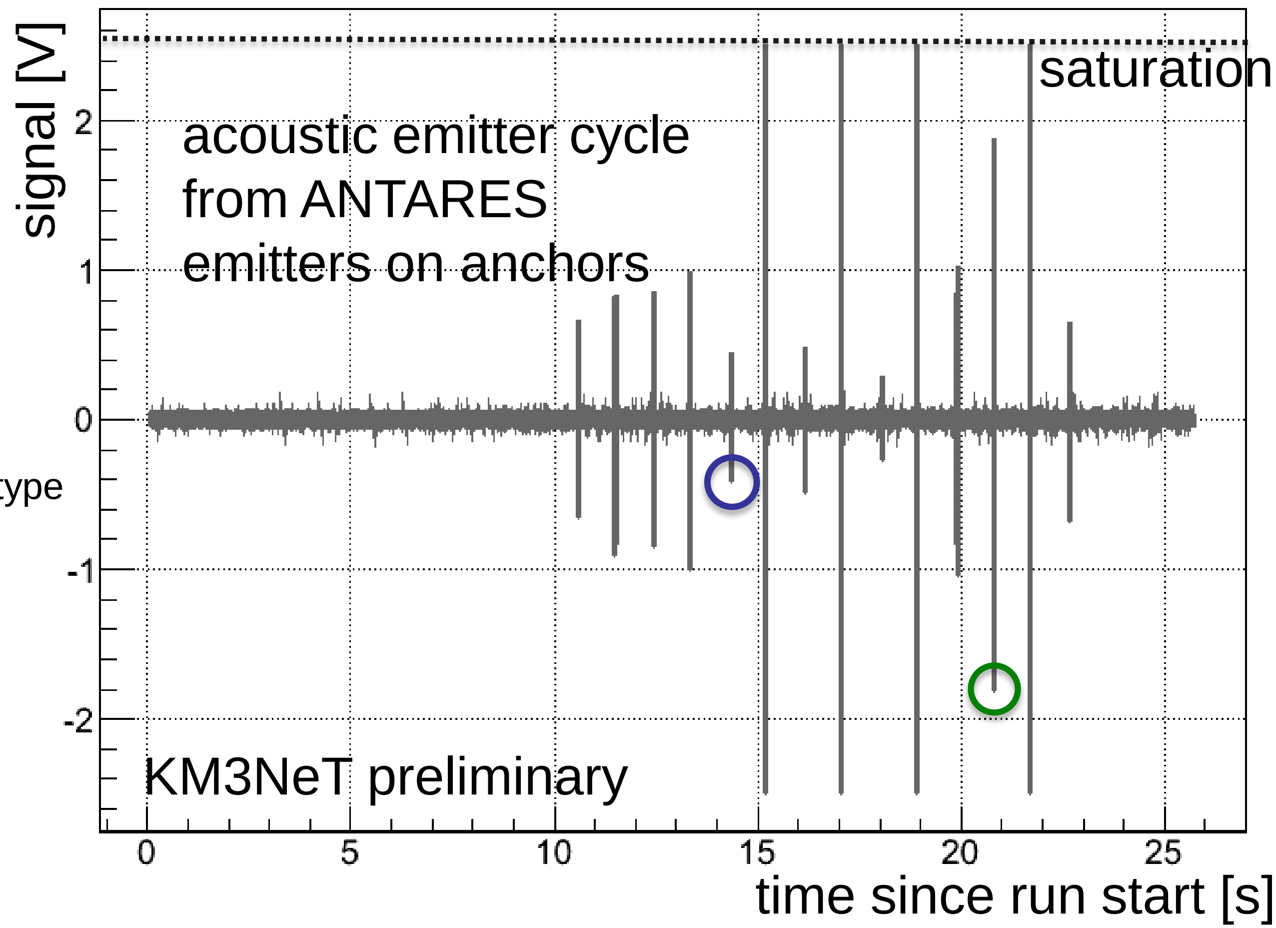




Acoustic Data from Prototype

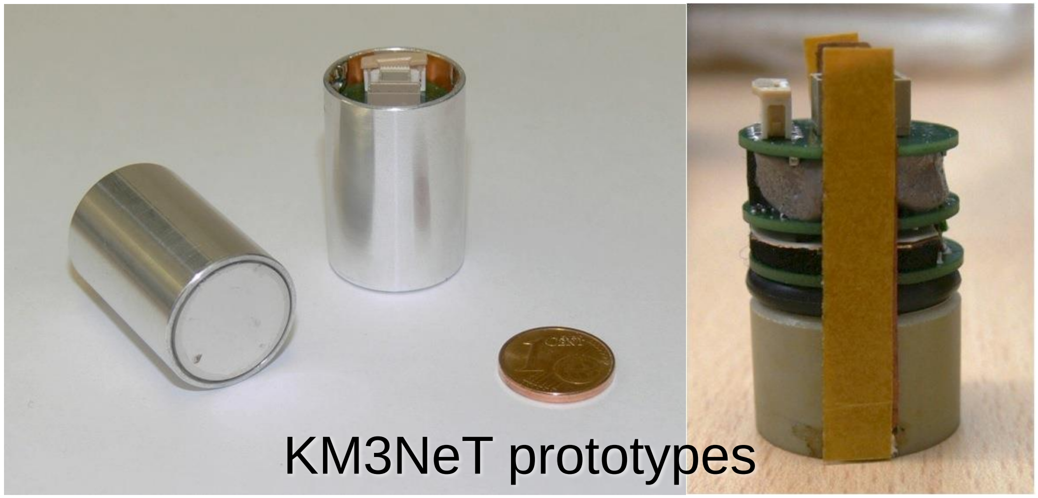


footprint
of ANTARES



⇒ allows for position calibration with $\mathbb{O}(5\,\mathrm{cm})$ statistical error

Digital Sensors



- Advantages:
  - compact design
  - easy to integrate into different systems due to digital interface
  - less susceptible to electromagnetic interference at signal transmission
- Disadvantages of digital sensor:
  - higher power dissipation (~400 mW) in small volume
  - depending on external readout (clock) – can be integrated

Digital Sensor Characteristics

piezo ceramic (PZ 27 disc, Ø=18 mm, h=11.5 mm)

↓

pre-amplifier (2-stage)

↓

high-pass filter

↓

ADC (sigma-delta AD7764, 24bit, 4V)

↓

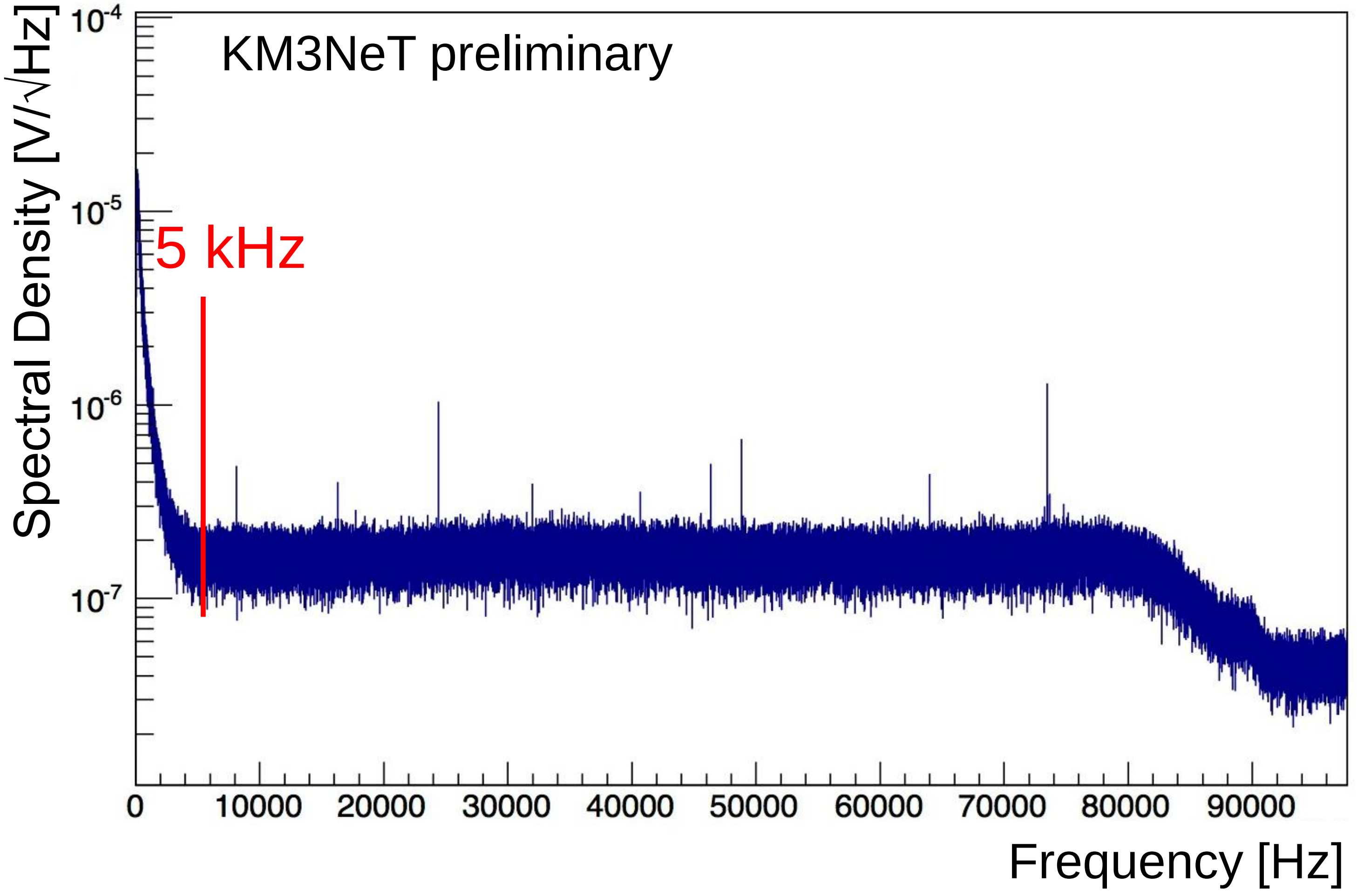
FPGA (ICE40LP1K, AES-3 output)

↓

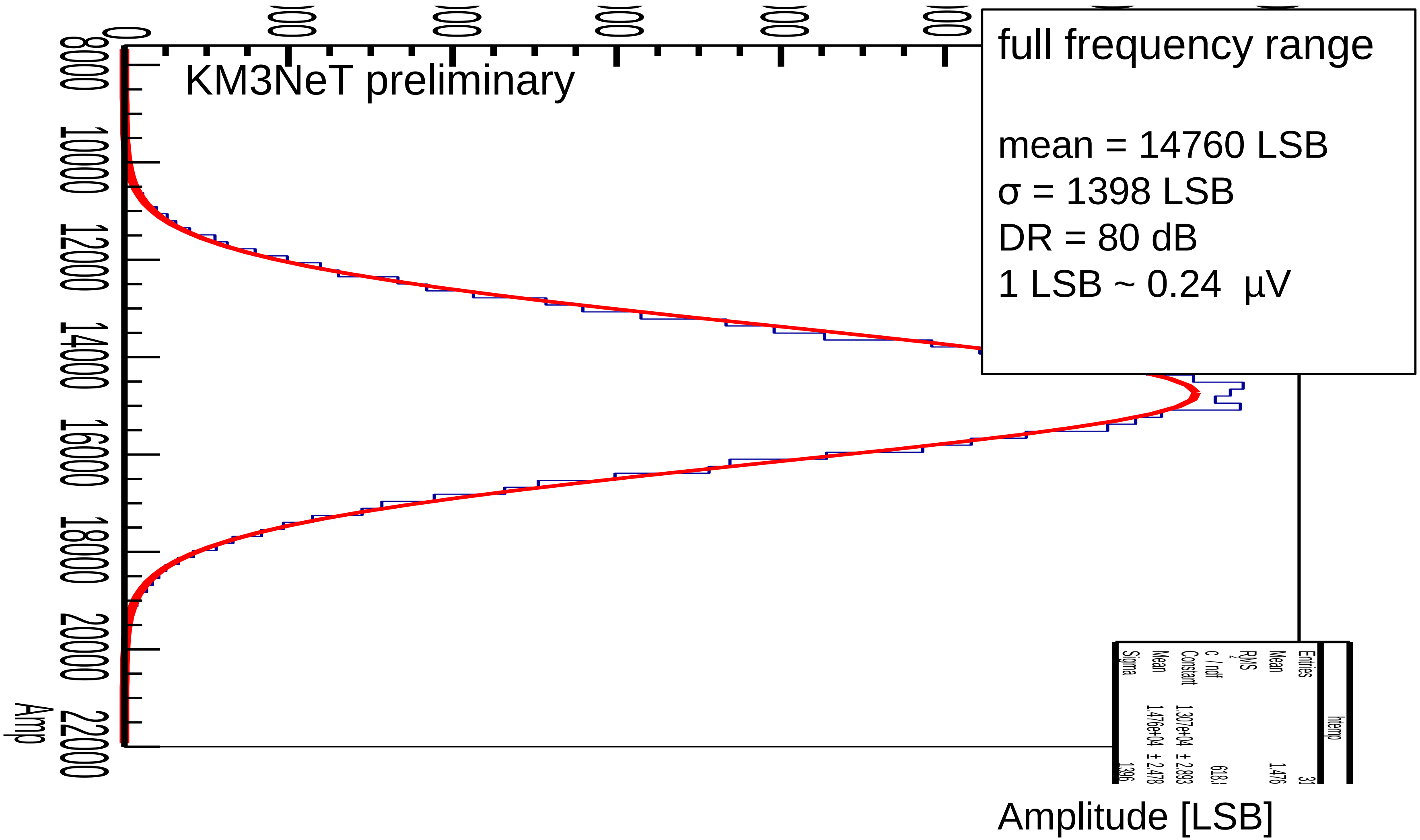
interfaces (clock in, read out, programming)

- Characteristics
  - versatile digital interface – adaptable
  - ~190kSps sampling rate (5 – 80 kHz flat response) – adaptable
  - low noise: $\mathbb{O}\left(100\,\mathrm{nV}/\sqrt{\mathrm{Hz}}\right)$
  - high sensitivity: $\mathbb{O}\left(-160\,\mathrm{dB}\ \mathrm{re}\ 1\,\mathrm{V}/\mu\mathrm{Pa}\right)$ – adaptable

Laboratory Measurements



Laboratory Measurements



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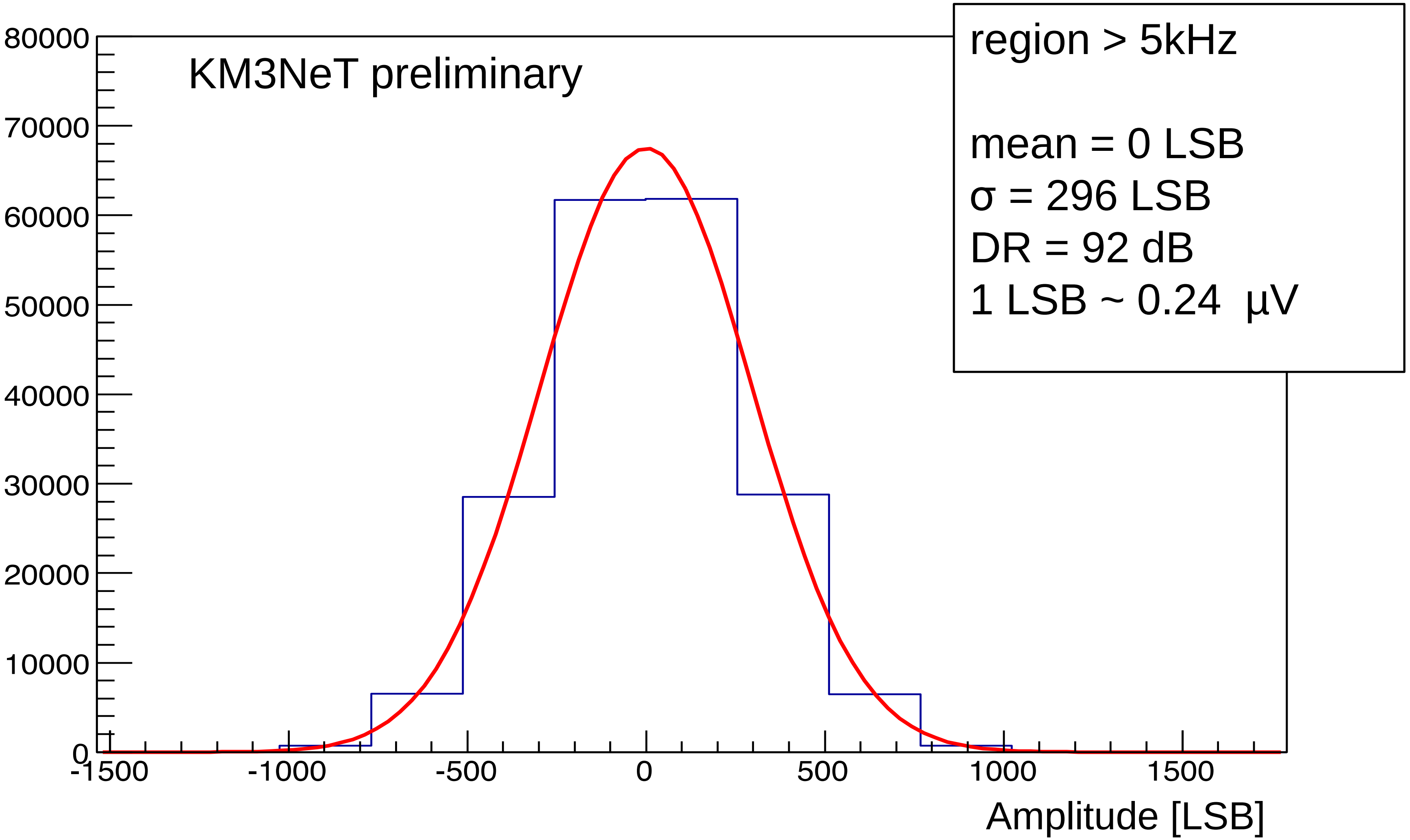

Next Steps and Additional Possibilities

- 10 prototypes produced
- started production of 600 digital sensors for first phase of KM3NeT
- testing and integration until end of 2014

- Characteristics
  - wide frequency band
  - high sensitivity, low noise
  - versatile due to programmable digital interface

  allow for different fields of application:
  - position calibration
  - (deep) water bio-acoustics, acoustic pollution
  - acoustic neutrino detection
  - …
- application as digital hydrophone possible – coating of sensor

Summary and Conclusion

- developed digital acoustic sensor for underwater applications
- primary application: position calibration for the future KM3NeT neutrino telescope
- compact and versatile design
- characteristics allow for different fields of application:
  - acoustic position calibration
  - marine science
  - acoustic particle detection

Detection Units (DUs)

- vertical unit of the detector:
  - underwater buoy, anchor
  - 2 Dyneema©-ropes (ø 4 mm)
  - 18 digital optical modules (DOMs), 36m vertical distance
  - total height ~700m
- electro-optical cable:
  - flexible hose (ø 6mm)
  - oil-filled
  - contains optical fibres and copper wires