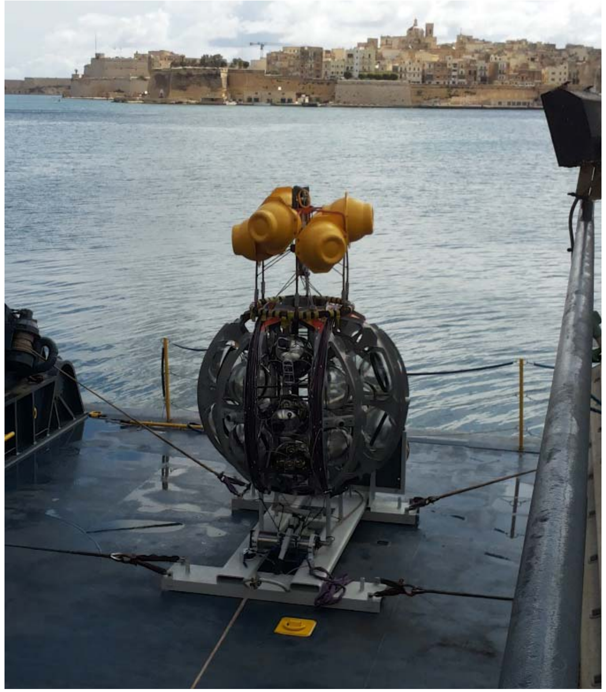
KM3NeT
The next generation neutrino telescope in the Mediterranean

In this talk:

- motivation for high-energy astronomy in the deep-sea (very briefly!)
- technical solutions for KM3NeT: Digital Optical Modules and Detection Units
- status & plans:
    - o qualification
    - o "Phase-1"
    - o next phases (including "ARCA" and "ORCA", aimed respectively at: high-energy neutrino astronomy and measurement of neutrino mass hierarchy)



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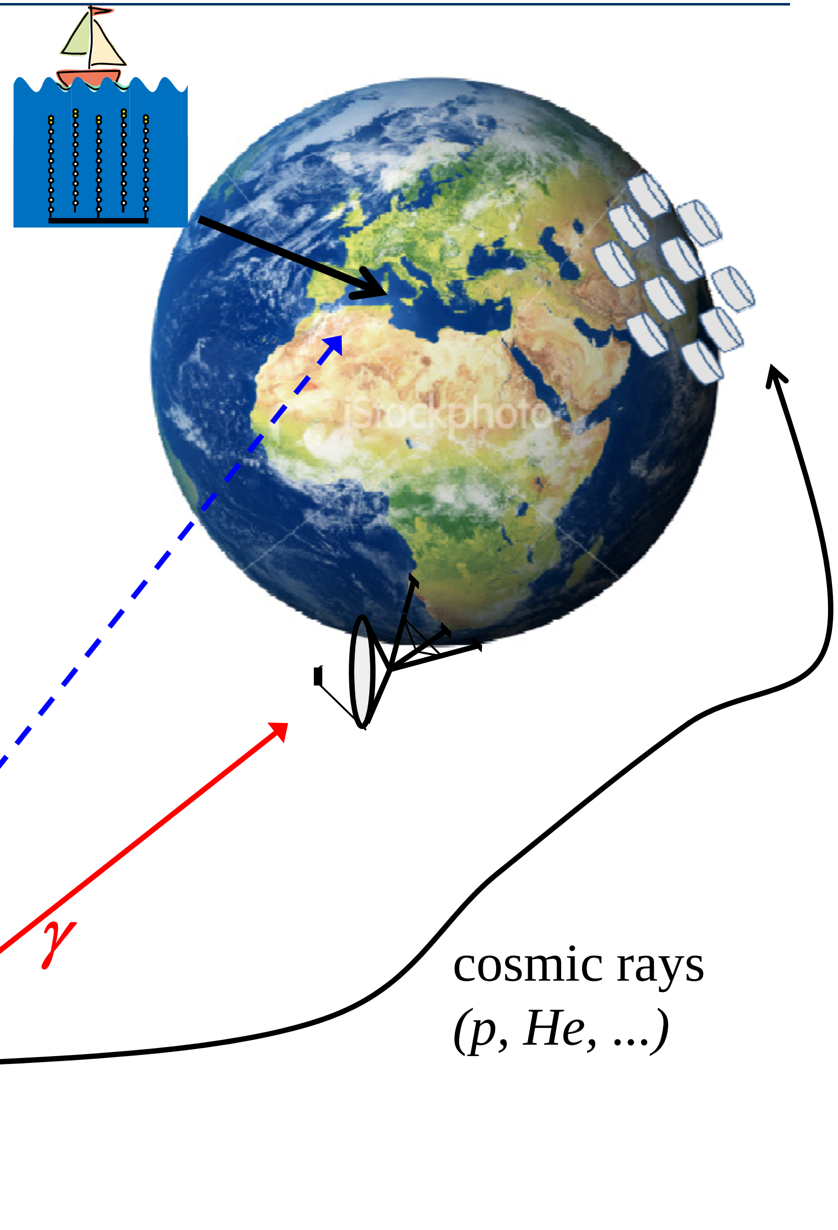
Neutrino telescopes for high-energy astrophysics

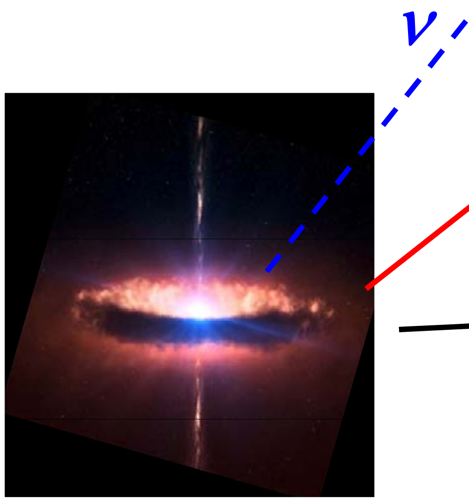
The concept: use neutrinos to unambiguously identify sites of hadronic acceleration in the Cosmos

The approach: to build a very large Cherenkov detector in a deep transparent medium (water or ice)

Evidence of cosmic neutrinos reported from IceCube at Antarctica opened the era of neutrino astronomy

Remark: the Mediterranean Sea is an ideal location to look at the Galactic Plane, including the Galactic Center (with very good angular resolution)

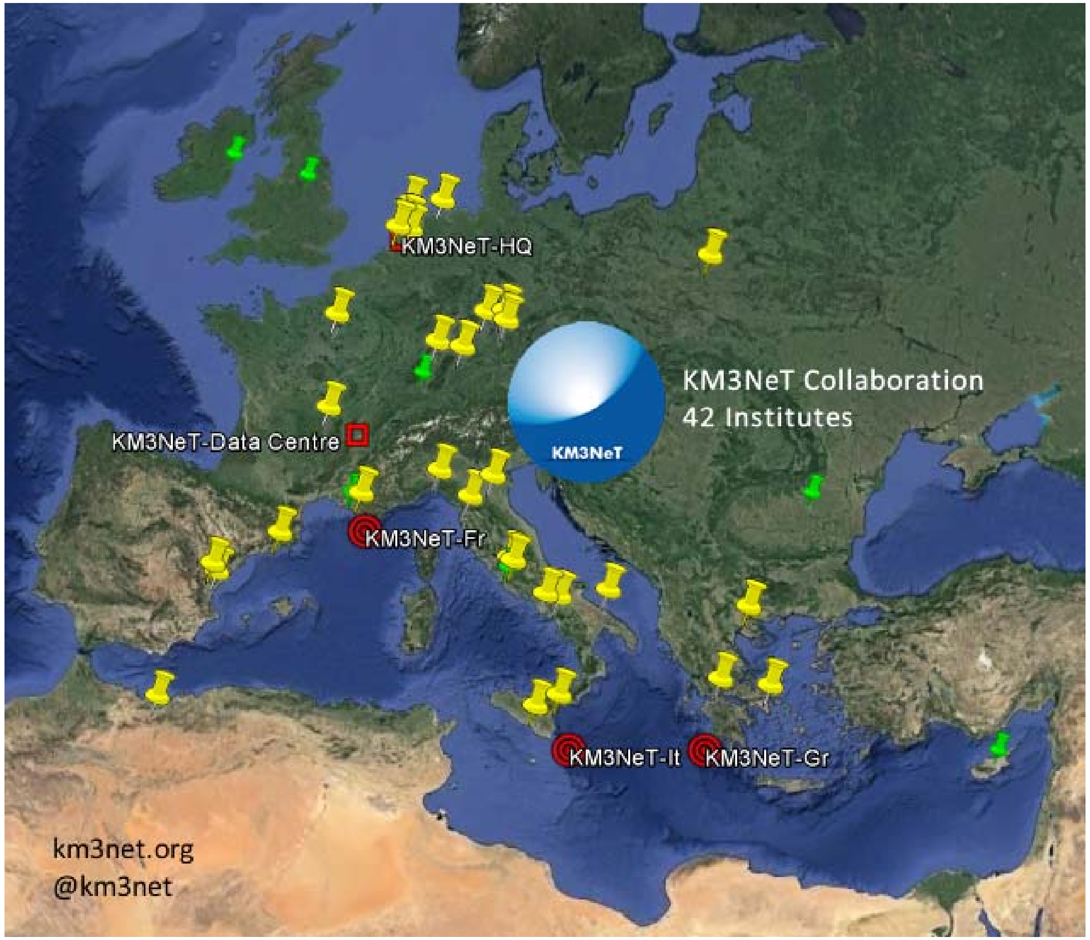




The KM3NeT research infrastructure

The Collaboration comprises ~300 researchers from more than 40 institutes in 11 countries (Cyprus, England, France, Germany, Greece, Ireland, Italy, Morocco, the Netherlands, Romania, Spain)

Multi-site installation:
Fr: 40 km offshore Toulon (2500 m depth)
It: 80 km offshore Capo Passero (3500 m depth)
Gr: 20 km offshore Pylos (> 4000 m depth)



Nodes for astrophysics and marine science at each site

Infrastructures at KM3NeT-Fr and -It

KM3NeT-Fr

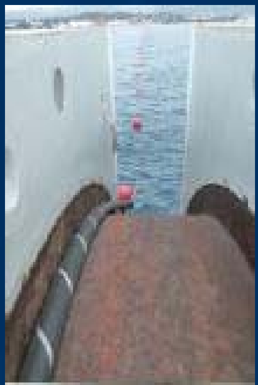
- Main electro-optical cable installed (Dec. 2014)
- Submarine node deployed (April 2015)
- Onshore station up and running

i.e.: infrastructure completed!

KM3NeT-It

- Main electro-optical cable installed years ago
- Prototype string in operation
- New cable termination frame and submarine junction boxes ready for deployment
- Onshore station ready
- Construction of 8 'tower' structures ongoing

i.e.: infrastructure up and running, about to be completed!



Deployment of the KM3NeT-Fr long-distance cable

Power station of KM3NeT-Fr

Shore station of KM3NeT-It

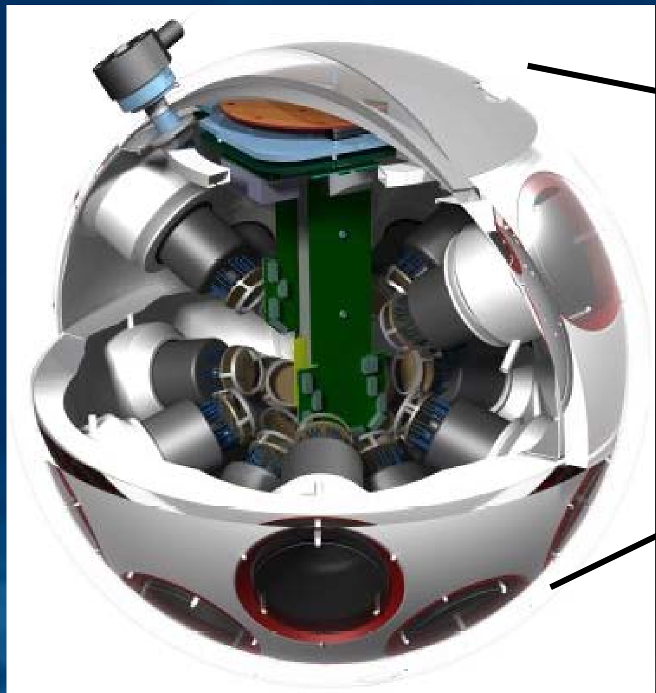
Deployment of node at KM3NeT-Fr

New cable termination frame for KM3NeT-It

DOMs and DUs

- 31 DUs (Detection Units) in Phase 1:
  - 24 DUs ("ARCA layout") in KM3NeT-It (~0.1 km^3 , ~3 x ANTARES)
  - DU-1 plus 6 more DUs ("ORCA layout") in KM3NeT-Fr

- 18 DOMs (Digital Optical Modules) on each DU, spaced by 36 m (in "ARCA layout")



More on Digital Optical Modules

- 31 PMTs of 3” photocathode in a 17” glass sphere
- Optical gel coupling between PMTs and glass
- Reflection rings around the PMTs to increase detection surface
- Electronics, optics for long-range communications and calibration devices (including: ‘nanobeacon’ LED pulser, compass/tiltmeter, and piezo-sensor for acoustic measurements) installed inside the sphere – each DOM acting as an individual, autonomous detection node
- Connection to the rest of the apparatus requires two conductors (+12 V power) and one optical fibre through a single penetrator

The multi-PMT Optical Module: rationale

- Segmentation of the photocathode allows photon-counting with high background rejection
- Maximum photocathode area in a sphere
- Extend sensitivity to a large fraction of solid angle
- Directionality!
- Local triggers can be exploited
- Cost-effective solution! Comparing 31 x 3" PMTs to a single 10" PMT:

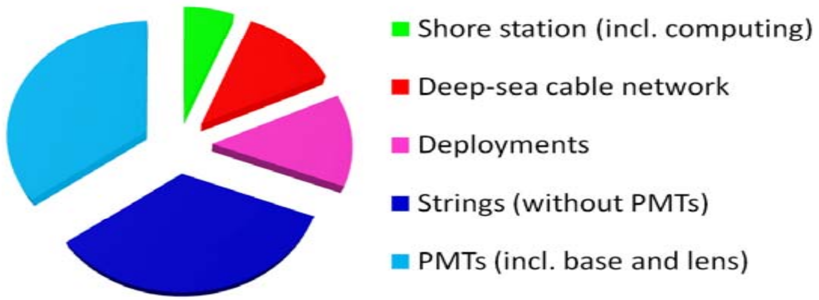
$31 \times \pi \times 1.5^2 / (\pi \times 5^2) =$ **2.8** **(ratio of phtocathode areas)**

=> need a factor of 2.8 fewer spheres, mechanics, electronics, network

(it also turns out that the price per unit photocathode area is cheaper for the 3" PMTs)

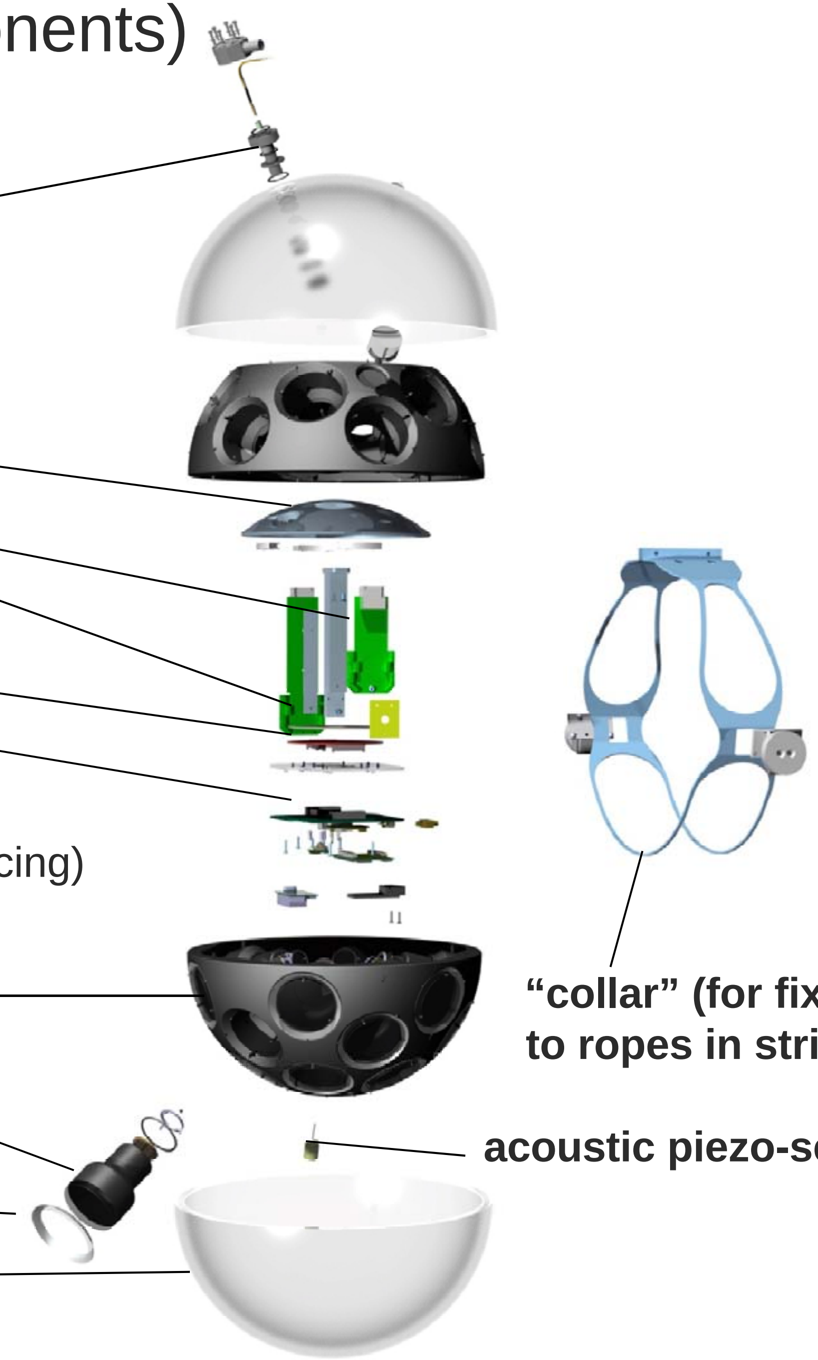

The ANTARES optical module
(single 10" PMT in a 17" sphere)


The KM3NeT DOM
(31 3" PMTs in a 17" sphere)



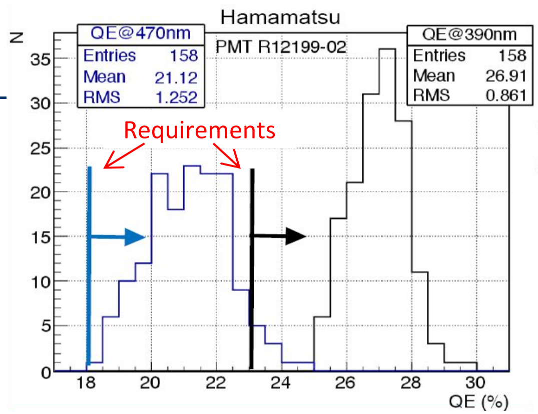
Breakdown of KM3NeT costs

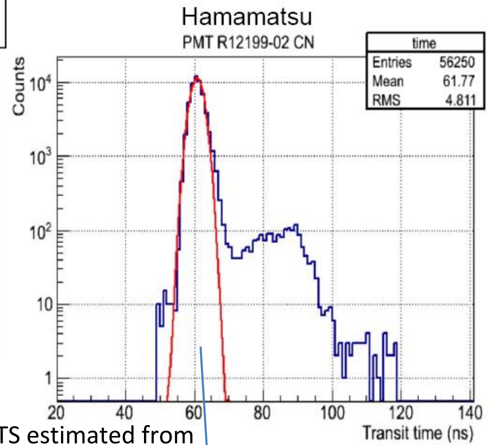
DOM design (major components)



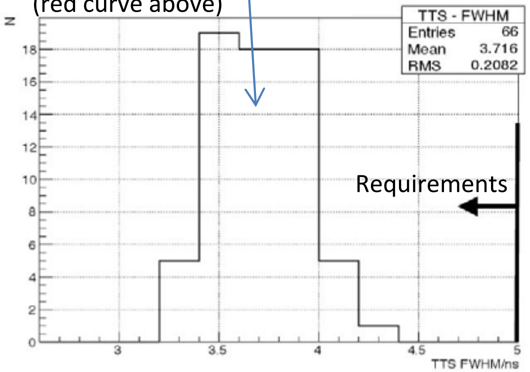
3" PMTs and readout

- timing ≤ 4.5 ns (FWHM)
- Q.E. ~30%
- collection efficiency ≥ 90%
- Various serious suppliers





TTS estimated from Gaussian fit of peak (red curve above)



Custom-design, low-power base allows to:

- Set HV on PMT (controlled from shore)
- Discriminate hits above threshold (controlled from shore)
- Send output signal to Central Logic Board (where Time-over-Threshold is digitized and time-stamped with 1 ns resolution)

⇨ All PMT hits sent to shore (no offshore filter)

ETEL D792

Hamamatsu R12199

HZC XP53B20

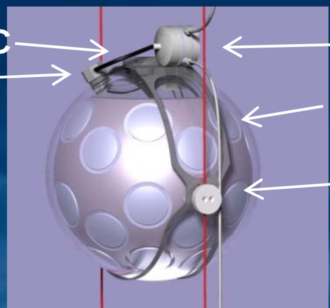
Detection units (DU)

- Mechanical structure of the string based on two dyneema ropes, anchored on sea floor and kept taught by a (commercial) top buoy (plus DOM buoyancy)
  - Robust and stiff arrangement
  - DOMs keep the correct attitude
  - String dynamics under control

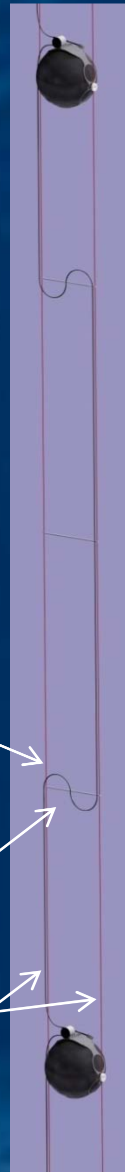
- the VEOC (Vertical Electrical-Optical Cable) connects all DOMs to the DU base – the VEOC is an oil-filled pressure-balanced hose equipped with 18 optical fibres (one for each DOM)

- DOM collars keep the DOMs in their positions

- A Break-out-box (BOB) is the interface between a DOM and the VEOC
  - Very simple structure hosting fibre splices and a DC/DC converter
  - A short cable (BEOC – BOB Electrical-Optical Cable) connects the BOB to the DOM penetrator



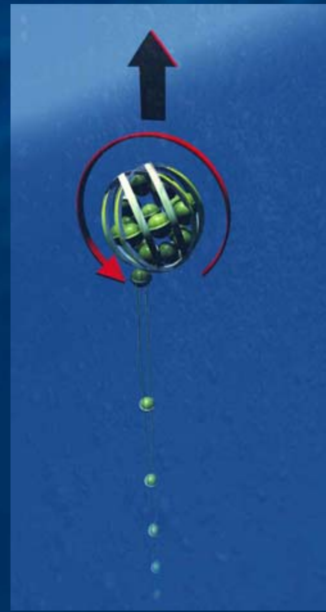
DOM and ropes



DU

Detection unit installation

- The detection unit is packed on a launcher vehicle (LOM) and installed on the anchor
- After deployment on sea bed, unfurling is done by operating an acoustic release
- LOM and acoustic release are recovered after operation



Unfurling!
(Artist's view - courtesy: Marijn van de Meer, Quest magazine)

Arrangement on LOM (detail)

Deployment time

ROV inspection of an unfurled structure

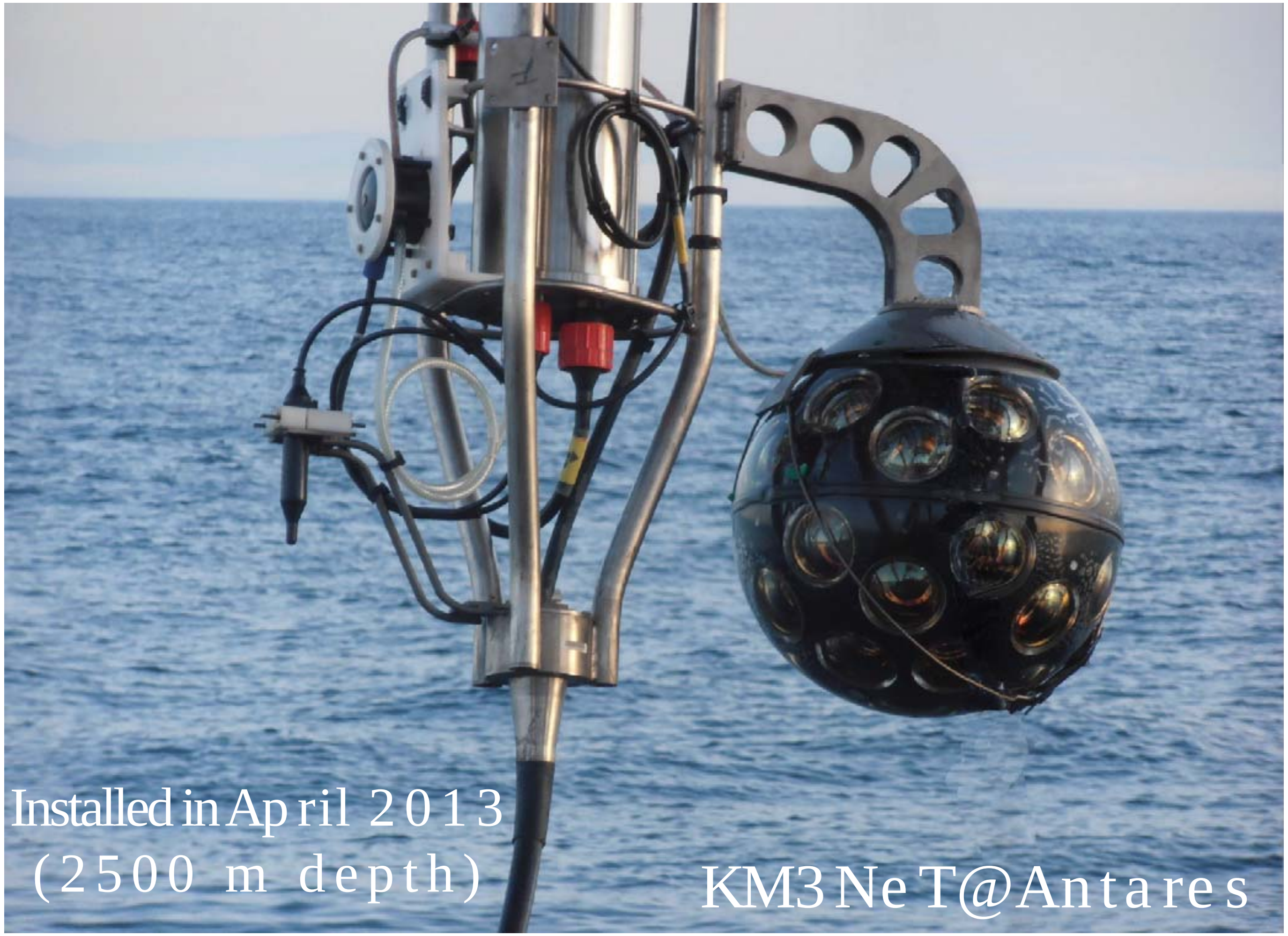
Qualification plan

Staged process:

- 1st prototype Optical Module (installed April 2013)
- 1st prototype string (installed May 2014)
- Installation tests (various sea campaigns done in past years + tests in the lab)
- Onshore qualification
- First Detection Unit

} being finalized

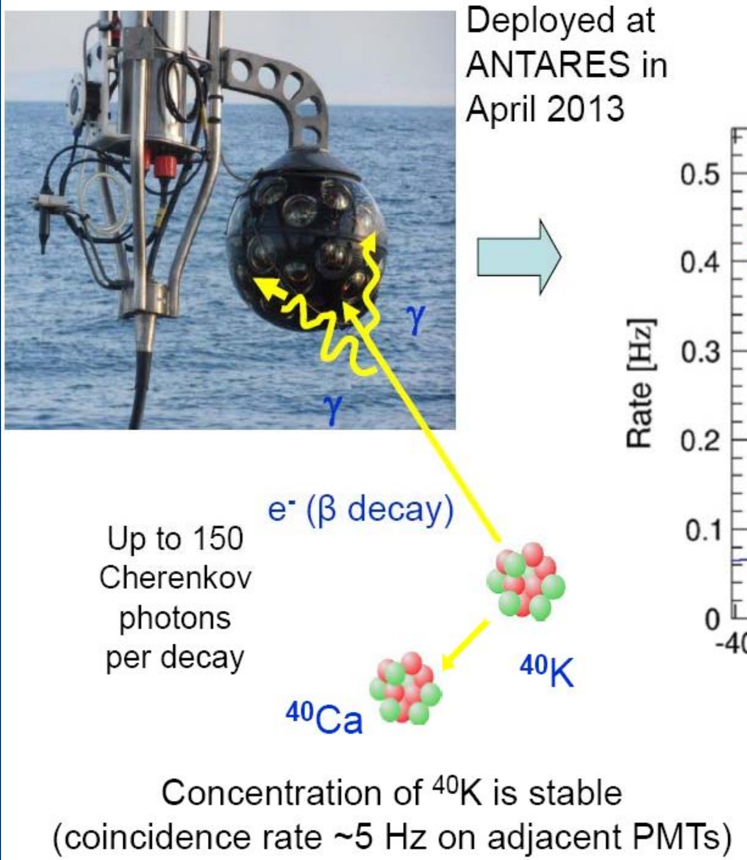
1st prototype Optical Module

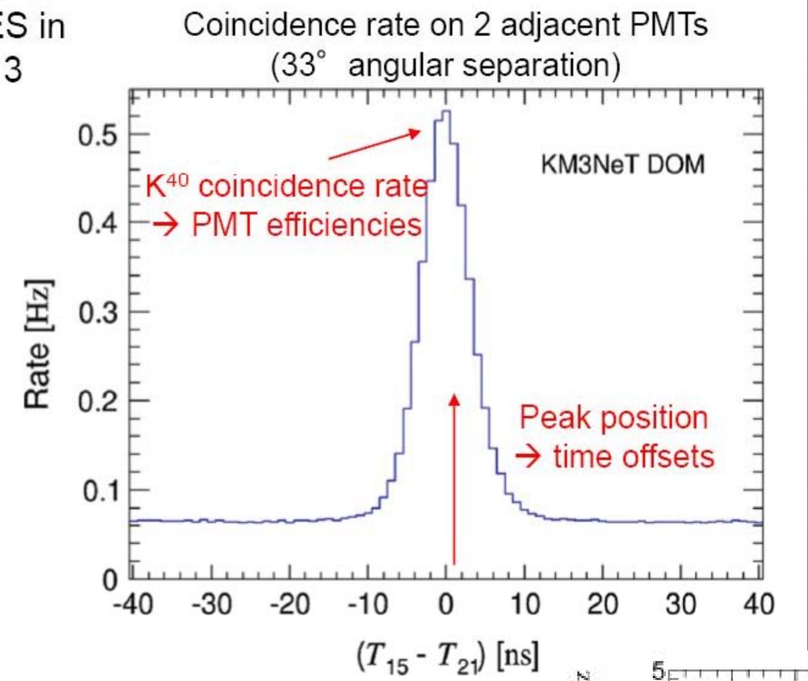


1st prototype Optical Module

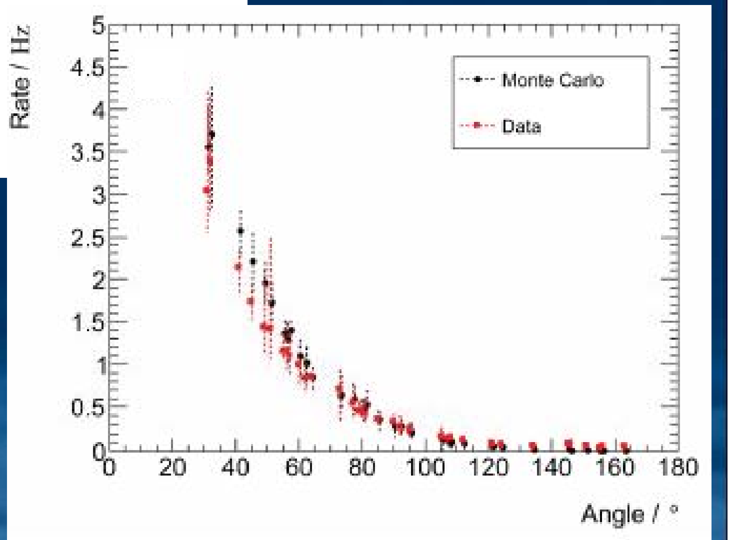
- all 31 channels working from the start
- worked fine and stably for more than 18 months

Results from PPM-DOM (I)





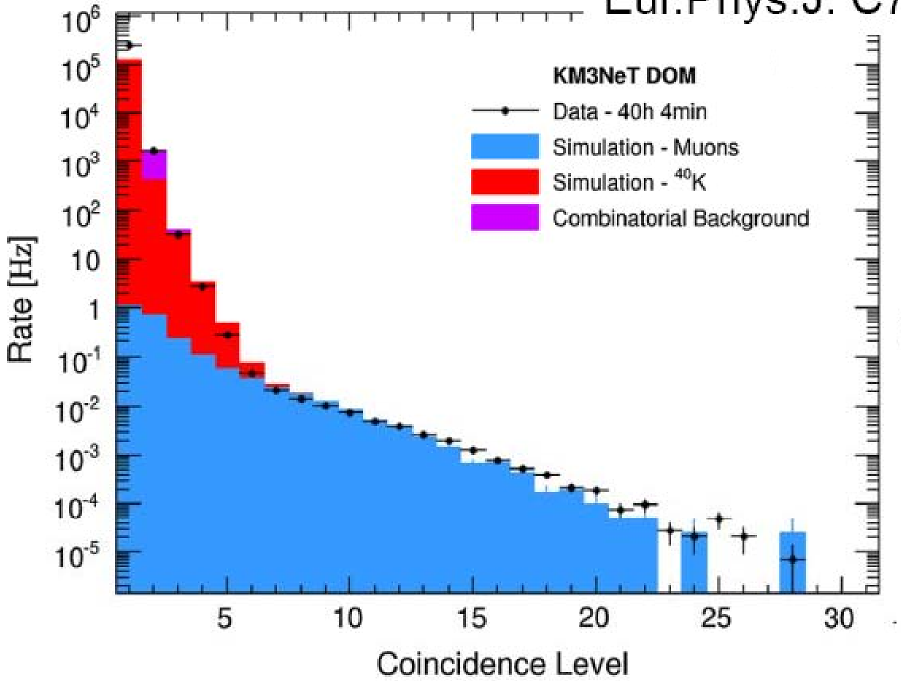
Ref.: Eur. Phys. J. C (2014) 74:3056



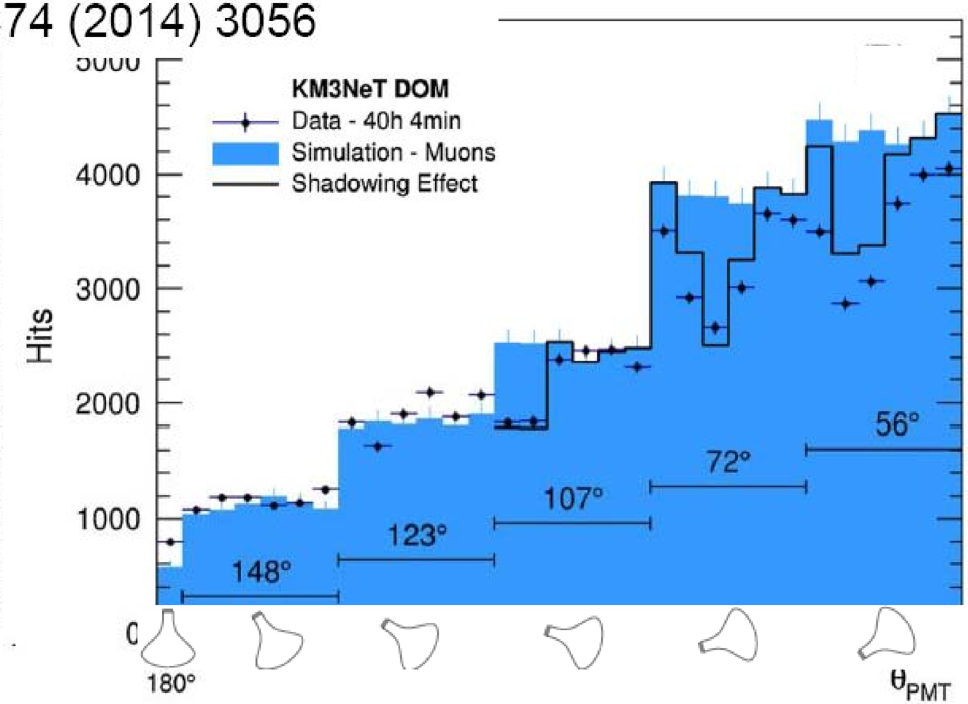
Coincidence rate vs.
difference in PMT orientation

Results from PPM-DOM (II)

Eur.Phys.J. C74 (2014) 3056



Number of coincident hits in a DOM

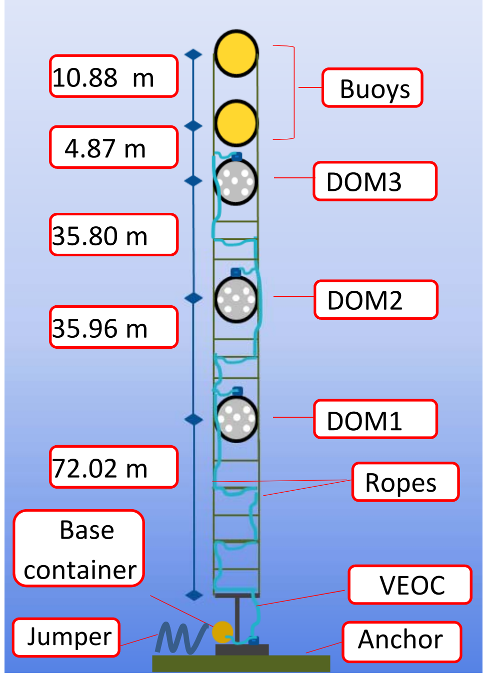


Zenith angle of hit PMTs in events with more than 6 coincident hits

>5 coincidences within 20ns ⇒ reduced K40 contribution, dominated by atmospheric muons

More upper PMTs in multi-hit events ⇒ directional information from single optical module

1st prototype string (3 Digital Optical Modules)



String configuration

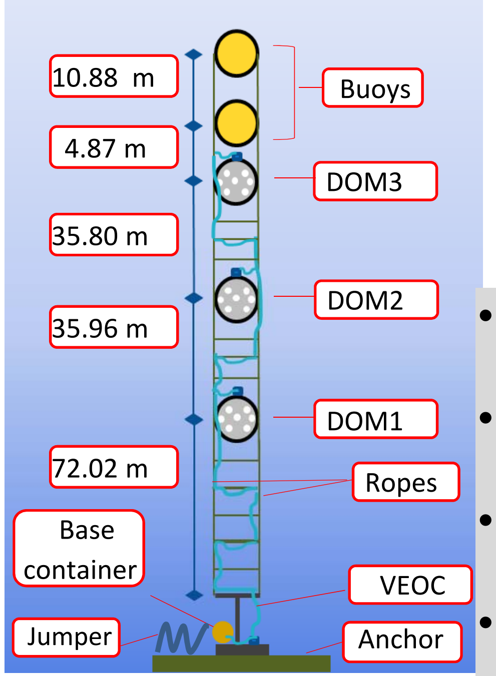
Integration of the 3 DOMs

Line ready for deployment

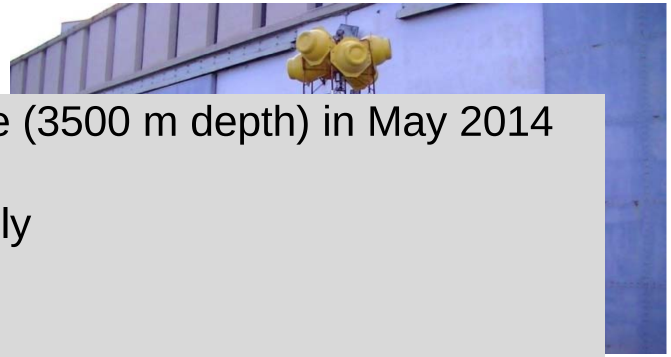
Deployment time!

ROV views of the operation: left – the ROV turns the structure in the best orientation for connection during deployment; right – connection done on the deep-sea infrastructure

1st prototype string (3 Digital Optical Modules)

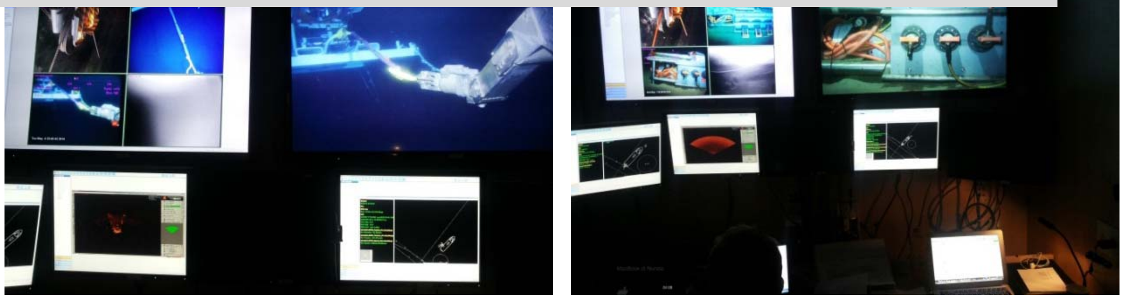


String configuration



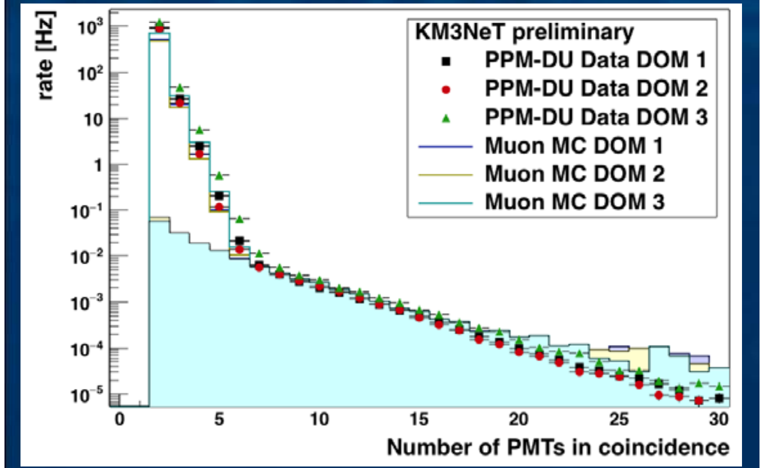
- Installed at the KM3NeT-It site (3500 m depth) in May 2014
- Installation went quite smoothly
- All 3 DOMs ok
- Smooth, stable operation in water
- Still taking data, with nice results! (Paper in preparation)

Deployment time!

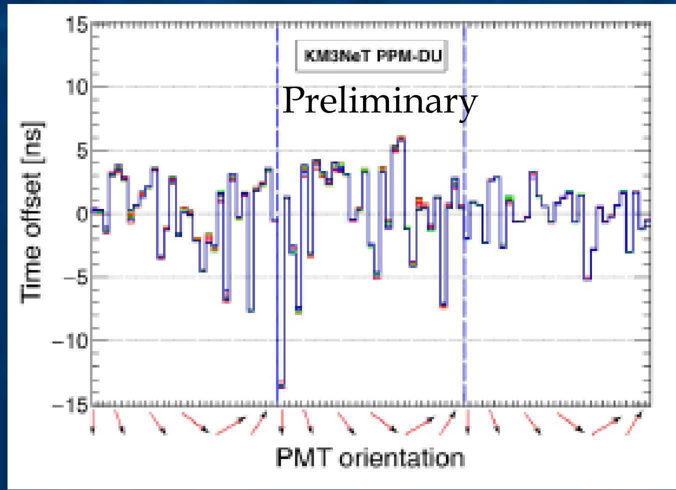


ROV views of the operation: left – the ROV turns the structure in the best orientation for connection during deployment; right – connection done on the deep-sea infrastructure

Results from prototype string



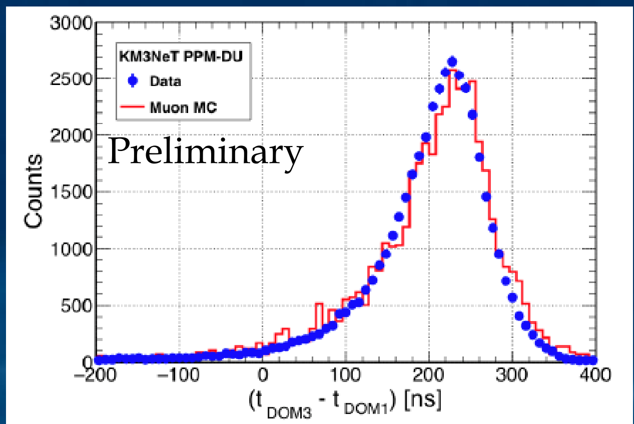
Hit coincidences inside DOMs



Time offsets from ^{40}K coincidences

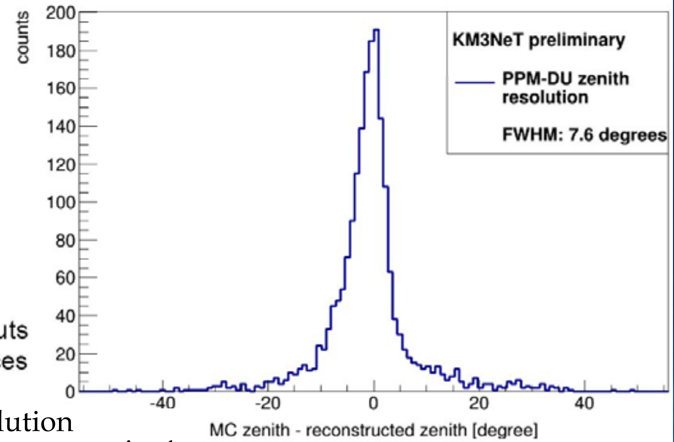
View of one DOM after 1 year in water… (from recent inspection)

- Good understanding of optical module performance
- Stability of DOMs studied, plus: inter-optical module time calibration and search for muons



Inter-DOM time differences

- Reconstruct muon trajectory from hits on 3 DOMs
- Ambiguities can be reduced by cuts on time differences



~7° FWHM resolution achieved – quite encouraging!

(reminder: we aim at 0.1° resolution with full detector)

Coming up next: first Detection Unit

- Integrated end 2014
- Extensive tests ongoing
- Plan: ready to deployment by mid-June

Calibration in dark room

Integration of first Detection Unit

Mock-up of anchor
used in test of submarine connection with ROV

Next step after Phase-1: KM3NeT 2.0

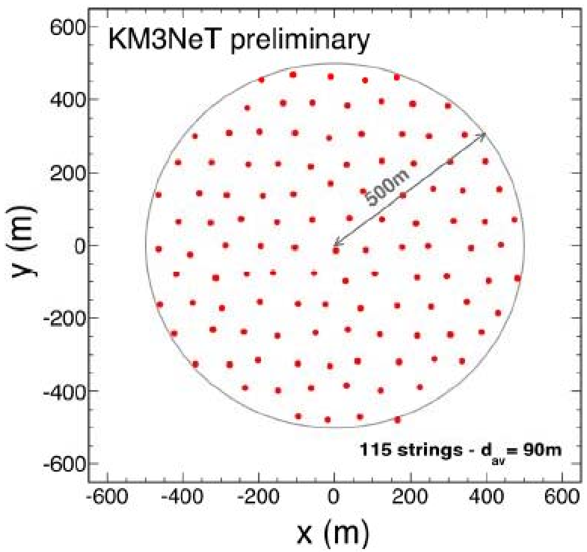
ARCA and ORCA

Vertical OM distance = 36 m

ARCA =

Astroparticle Research with Cosmics in the Abyss

(2 blocks of 115 detection units each, ~1-2 km^3)



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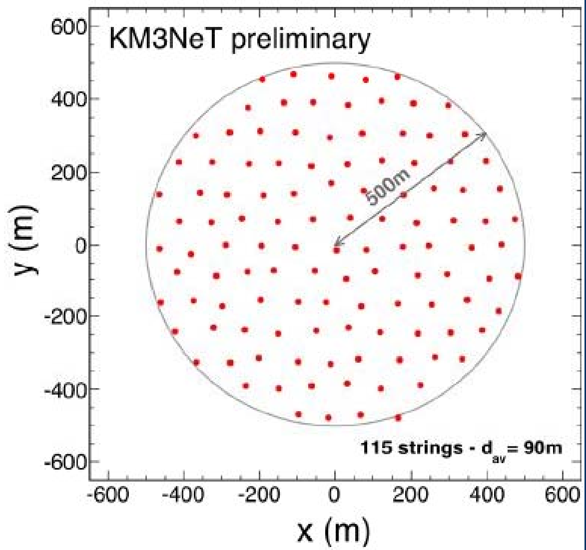
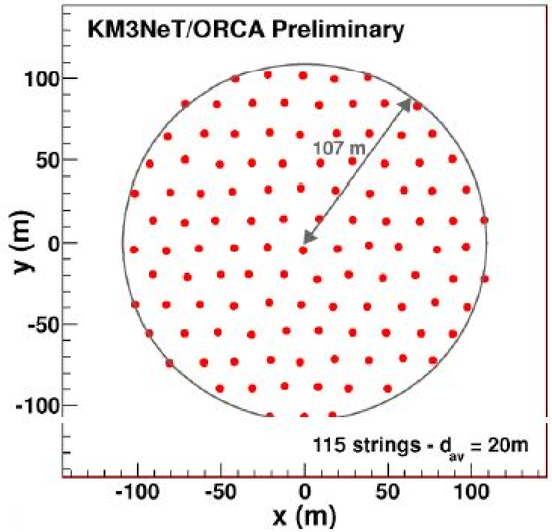


ORCA =

Oscillation Research with Cosmics in the Abyss

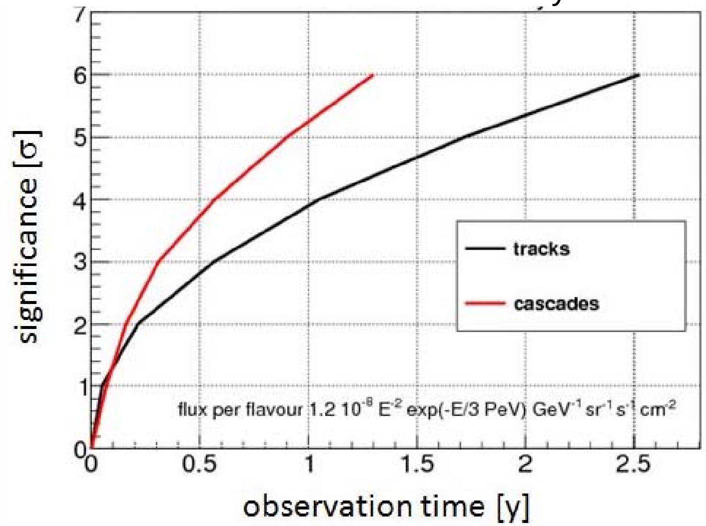
(1 block of 115 detection units)



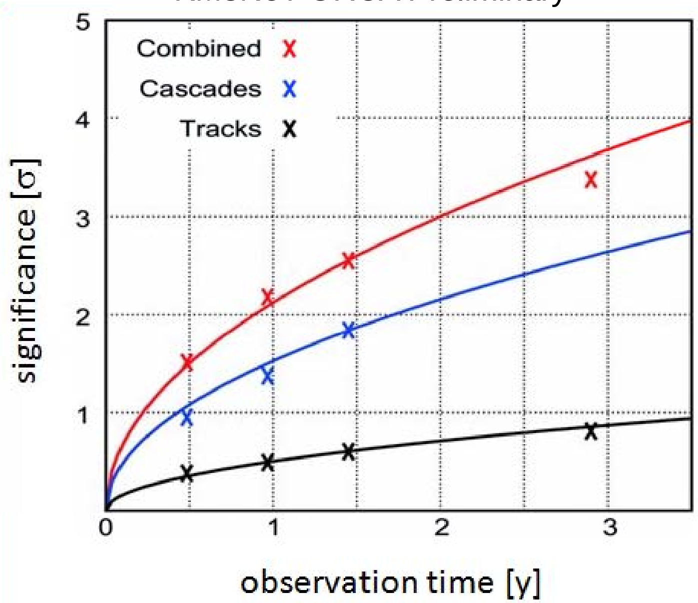
Vertical OM distance = 6 – 12 m

Next step after Phase-1: KM3NeT 2.0

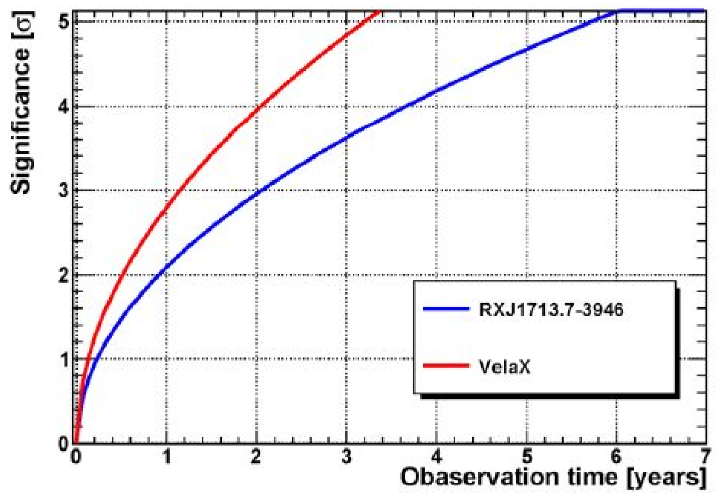
KM3NeT ARCA Preliminary



KM3NeT ORCA Preliminary



Full KM3NeT - (detector with 6 building blocks) - Preliminary



- All-flavour neutrino astronomy
- Precision measurements in neutrino physics
- Nodes for earth and sea science research

Concluding remarks

- R&D
  - developed cost-effective technology
  - feedback from prototypes confirm key specifications
  - qualification plan close to fulfilment
- Ongoing: Phase-1 (funded)
  - going ahead as planned, preparing to install first detection unit
  - infrastructures at KM3NeT-Fr and KM3NeT-It ready to accept connections...
- Next step: KM3NeT 2.0 (proposal)
  - *ARCA*
    - measurement of IceCube flux with different methodology, complementary field of view and improved resolution
    - all flavour neutrino astronomy
  - *ORCA*
    - measurement of neutrino mass hierarchy
- Final goal (Phase-3)
  - neutrino astronomy with multi-km^3 detector