KM3NeT

Portopalo di Capo Passero, 21 febbraio 2019

KM3NeT: un laboratorio sottomarino per lo studio dei neutrini

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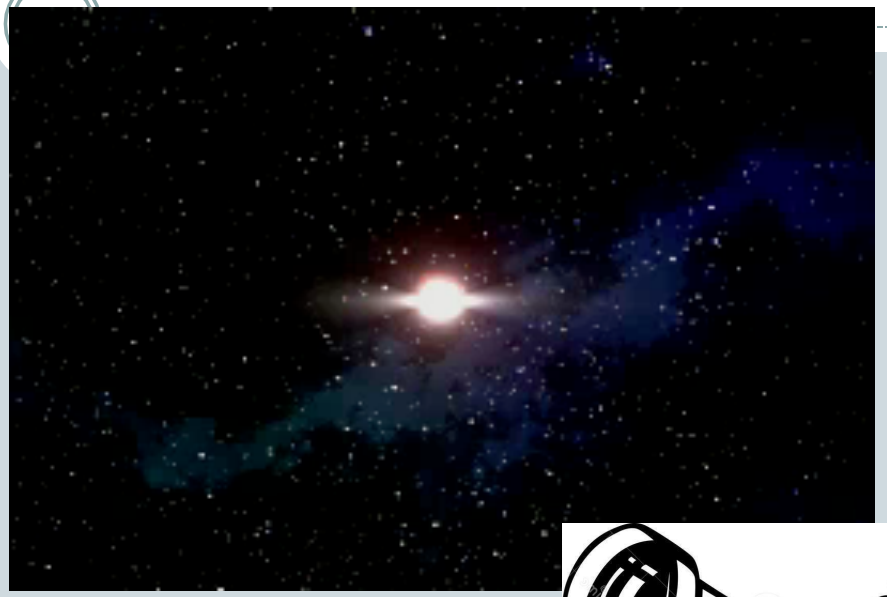
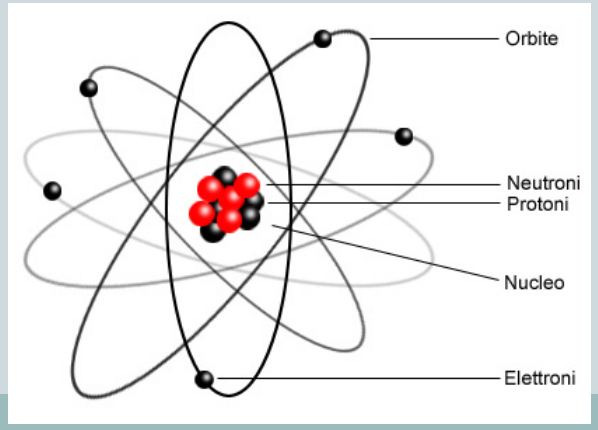
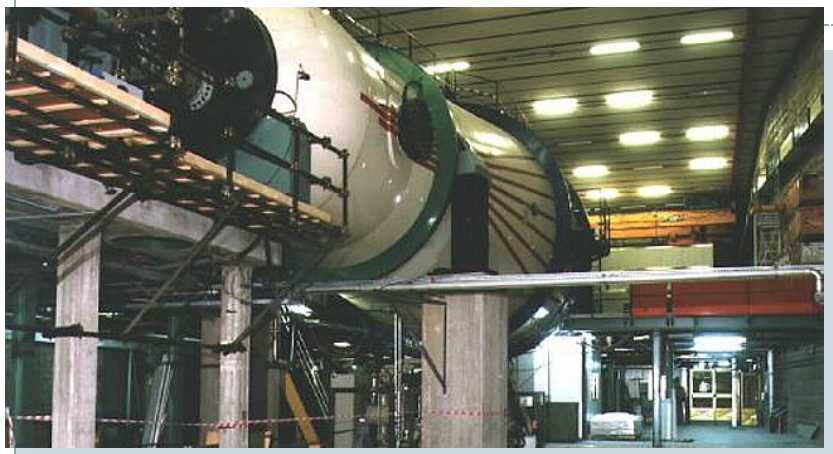
Fisica nucleare vs sorgenti astrofisiche



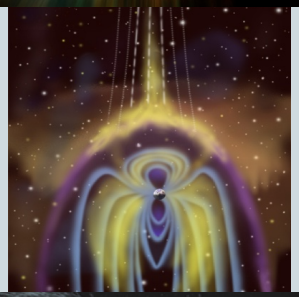


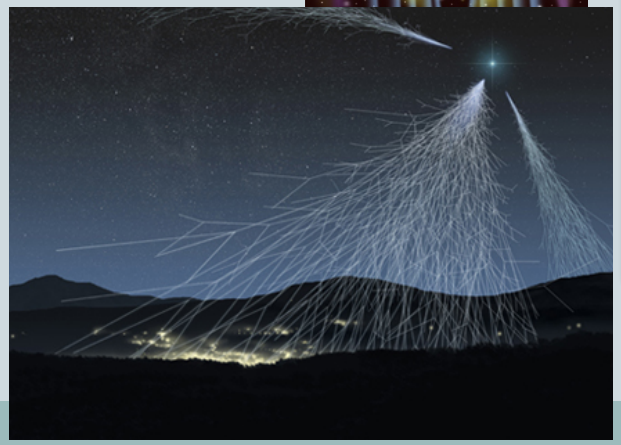
Cosa accomuna l'infinitamente piccolo con l'infinitamente grande?

Il “mestiere” del fisico nucleare



Riproduciamo e studiamo in laboratorio le reazioni nucleari che avvengono nelle stelle e nell'Universo…

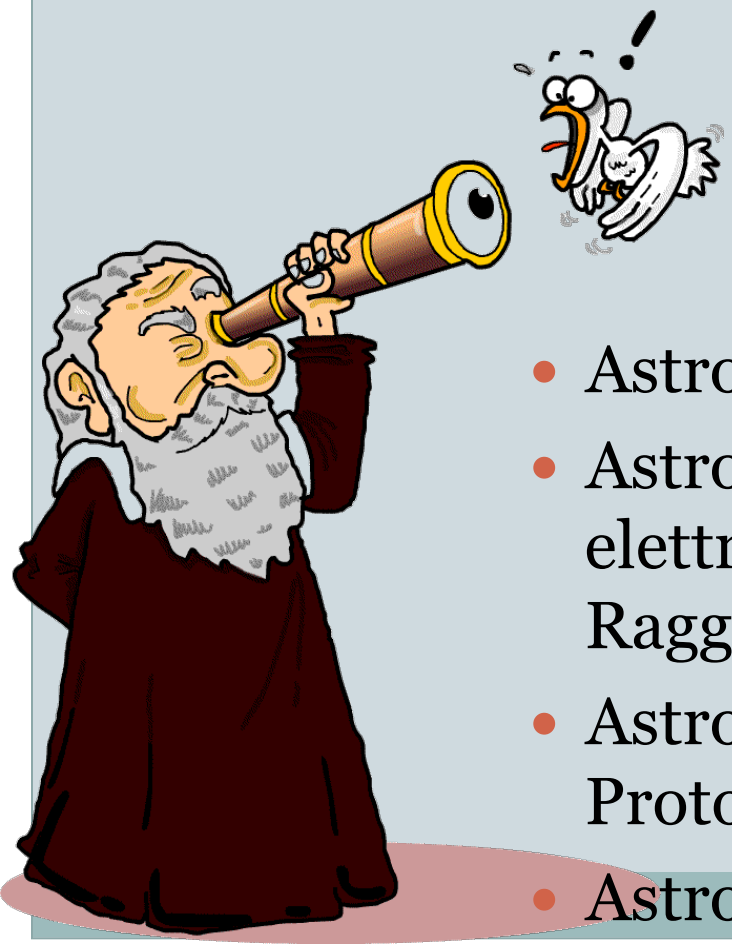




Riveliamo e studiamo la radiazione cosmica che arriva sulla Terra: “Acceleratori Naturali” !

Cosa significa fare astronomia?

Osservare e studiare oggetti e fenomeni cosmici!



Abbiamo bisogno di "occhi" specifici per sondare gli spazi più remoti dell'Universo!

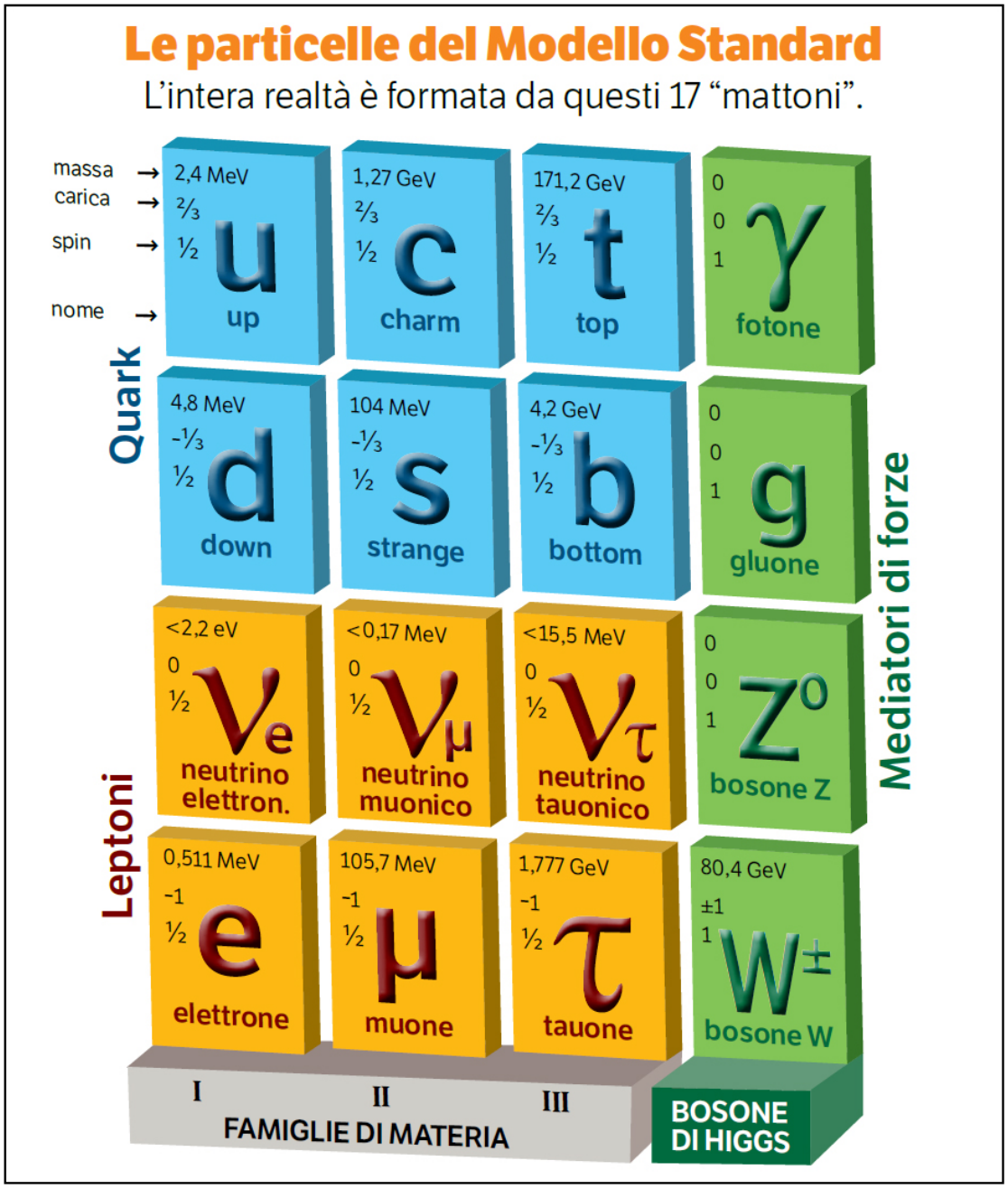
- Astronomia 'tradizionale' → Luce visibile
- Astronomia con 'radiazione elettromagnetica' → Onde radio, Infrarosso, Raggi X, Raggi Gamma
- Astronomia con raggi cosmici → Particelle: Protoni, Nuclei leggeri, Neutrini, ecc…
- Astronomia a onde gravitazionali!

Cosa significa fare astronomia?

Osservare e studiare oggetti e fenomeni cosmici!

Abbiamo bisogno di "occhi" specifici per sondare gli spazi più remoti dell'Universo!

- Puntamento direzionale
  - Riveliamo radiazione cosmica: studiamo le proprietà della sorgente e in particolare la sua **posizione**
- Orizzonte di osservabilità
  - È una stima della **distanza massima** degli oggetti cosmici dalla Terra indagabile con l'ausilio della particolare radiazione scelta.



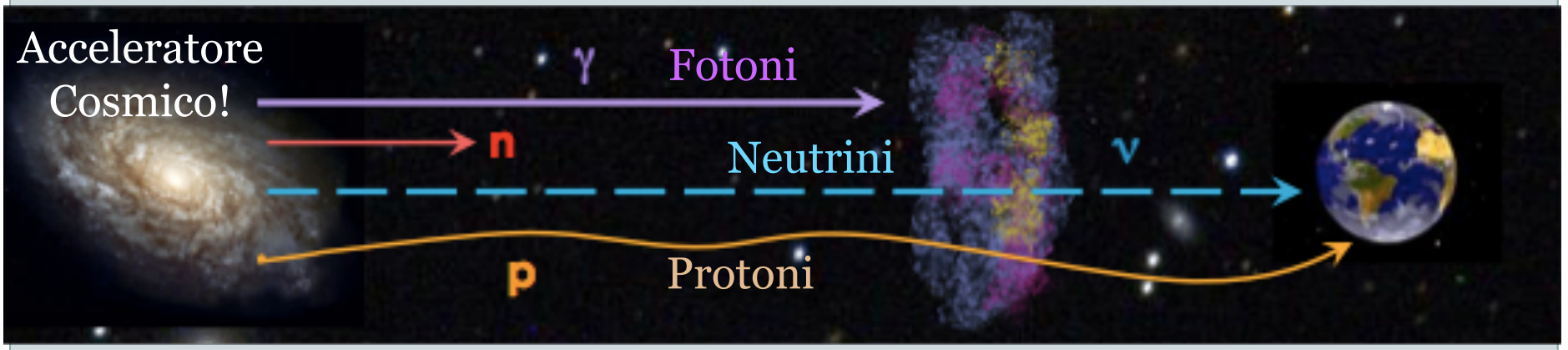
Il neutrino

- Il neutrino non ha carica elettrica
- Ha una massa molto piccola
- Interagisce molto poco con la materia, tramite la "forza debole"
- Attraversa quasi indisturbato la materia!

Fare astronomia con i neutrini di alta energia

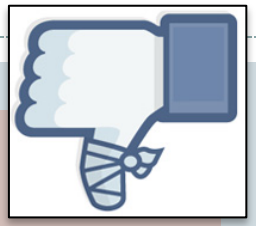
Vantaggi

- Il neutrino non ha carica elettrica e non viene deflesso da campi magnetici → Puntamento direzionale!
- Viaggia indisturbato attraverso l'Universo, trasportando informazioni sulla sorgente che lo ha prodotto → Orizzonte di osservabilità!



Alta energia significa → da 10^2 GeV a 10^8 GeV

Fare astronomia con i neutrini di alta energia



Svantaggi

- Il neutrino interagisce solo debolmente con la materia

  → Abbiamo bisogno di costruire **enormi apparati** per rivelarlo

- La radiazione cosmica 'disturba' la sua rivelazione

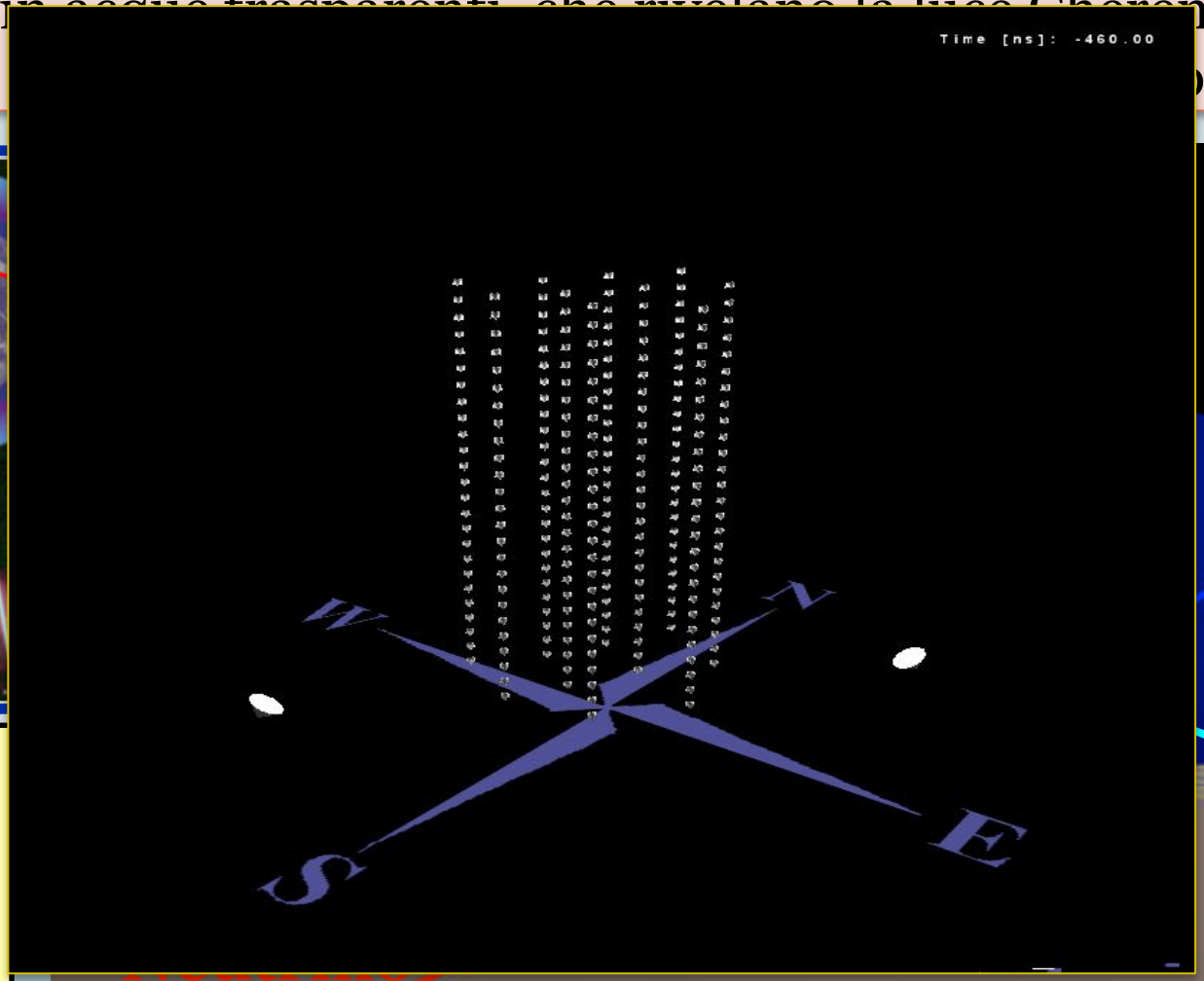
  → Dobbiamo costruire il nostro telescopio sotto le montagne o a **grandi profondità marine**

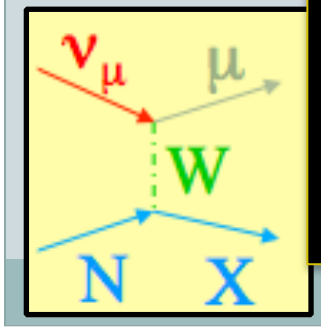
Soluzione: costruire apparati di grande volume (~km^3) nelle profondità marine, in laghi profondi o nei ghiacci antartici

Idea suggerita da Markov negli anni '60

Come funziona un telescopio per neutrini?

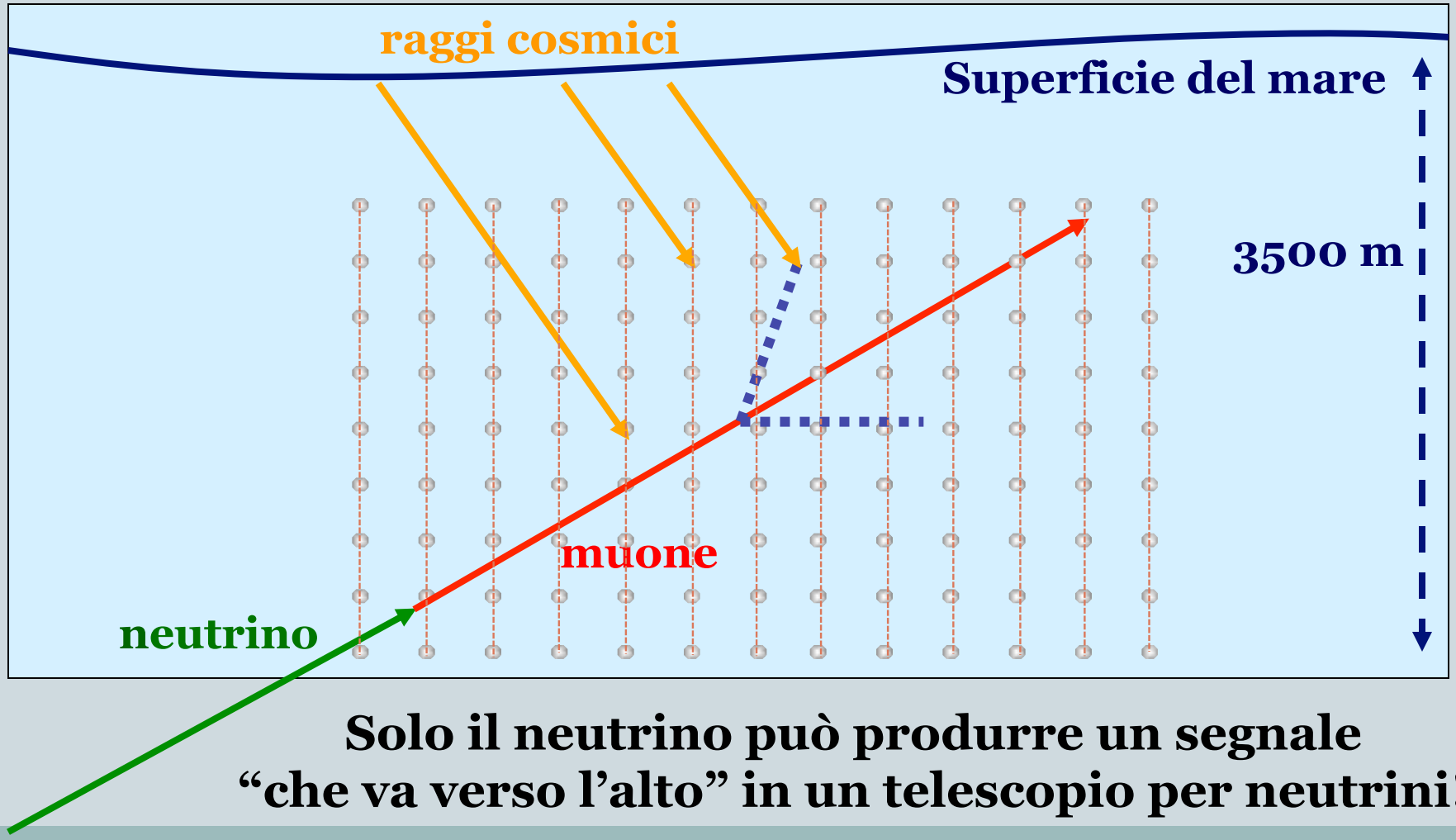
È costituito da un reticolo di “occhi elettronici” (i fotomoltiplicatori), installato in acque trasparenti, che rivelano la luce Cherenkov emessa





Come funziona un telescopio per neutrini!

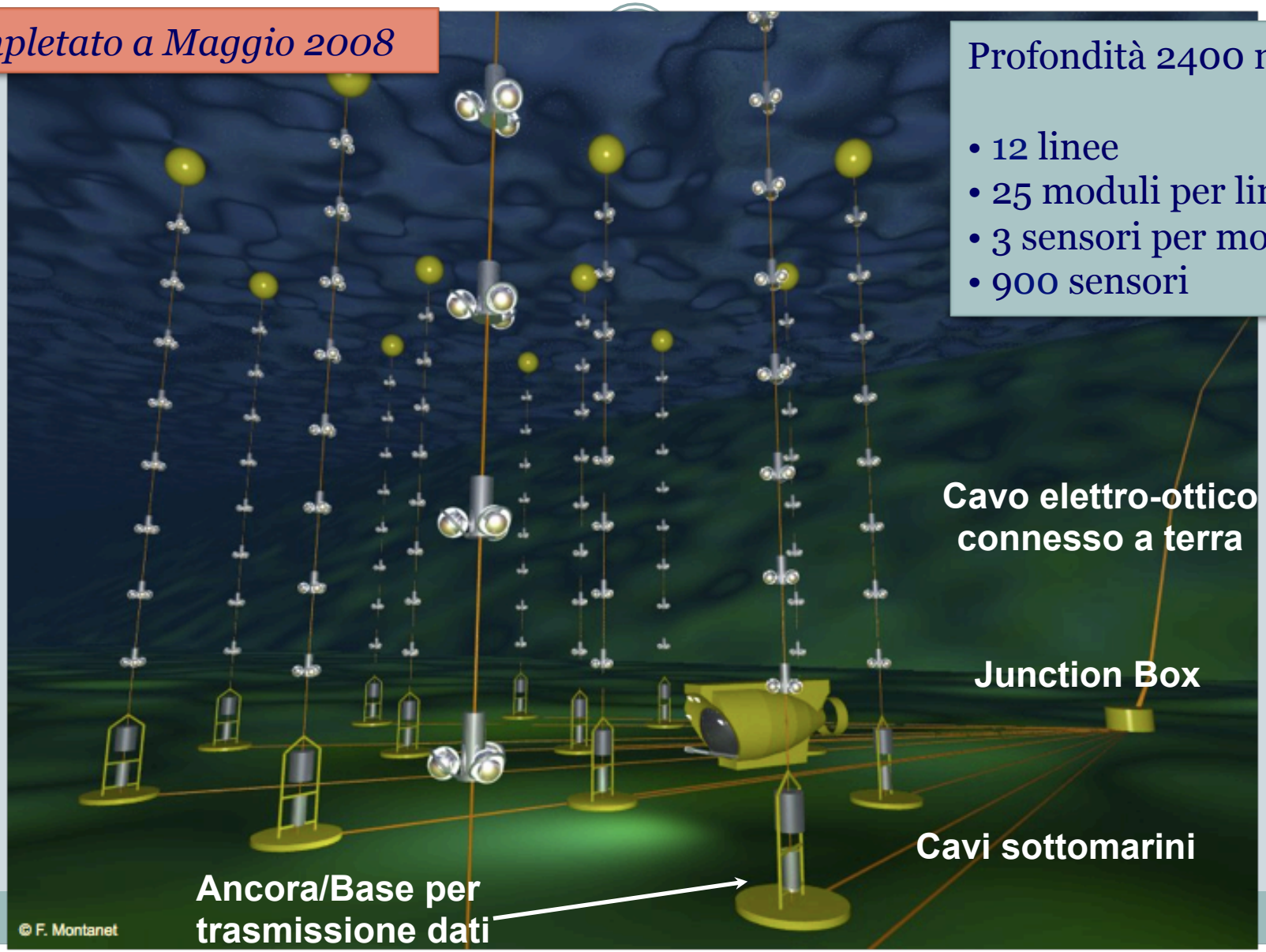
Un telescopio… che guarda sotto i piedi!



Solo il neutrino può produrre un segnale "che va verso l'alto" in un telescopio per neutrini!

Il telescopio prototipo 'ANTARES' (Tolone)

Completato a Maggio 2008



Il futuro: KM3NeT

- Una collaborazione internazionale di circa 40 istituti da 10 paesi europei
- Sito di installazione: una piattaforma abissale a 3500 m di profondità, a 80 km di distanza da Portopalo di Capo Passero (SR).

KM3NeT

KM3NeT is a multisite infrastructure in the Mediterranean Sea hosting neutrino detectors

- **KM3NeT-ARCA** (*Astroparticle Research with Cosmics in the Abyss*)
  - Discovery and observation of high energy (GeV ÷ PeV) neutrino sources → a telescope offshore **Capo Passero** (**Sicily-Italy**) is in construction at a depth of 3500m
- **KM3NeT-ORCA** (*Oscillation Research with Cosmics in the Abyss)*
  - Determination of the neutrino mass hierarchy → a detector offshore **Toulon** (**France**) able to detect neutrinos of tens of GeV is in construction at a depth of 2500m

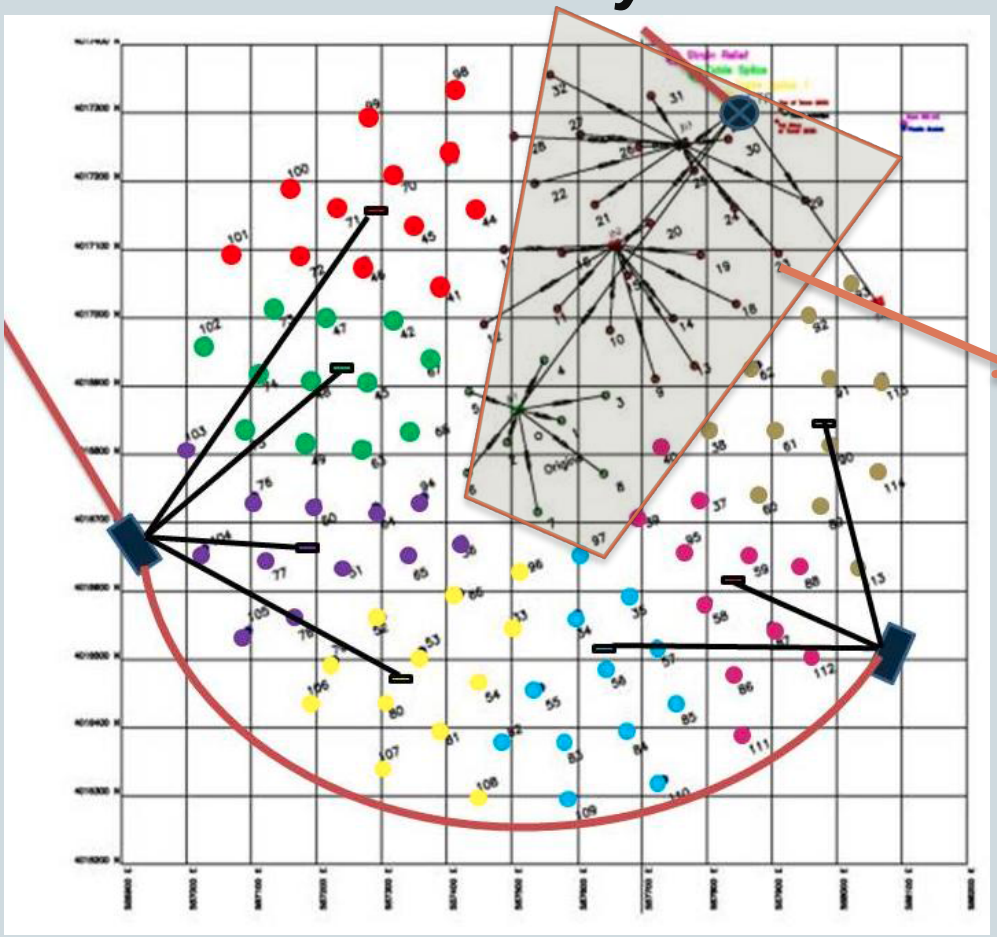
ORCA and ARCA same detector technology

The KM3NeT scientific aims

- KM3NeT is a multi-purpose submarine laboratory
  - Distributed infrastructure in deep waters of Mediterranean Sea (multi-site option)
  - On-shore cable connected observatories
  - Neutrino telescope >1 km^3
- KM3NeT-ARCA extends our knowledge of the Universe
  - Study of neutrino point sources
  - Measurement of cosmic neutrino diffuse fluxes
  - Multi-messenger approach
  - Dark matter, neutrino oscillations, 'exotics'
  - Synergy with Earth and Sea sciences

KM3NeT-It site

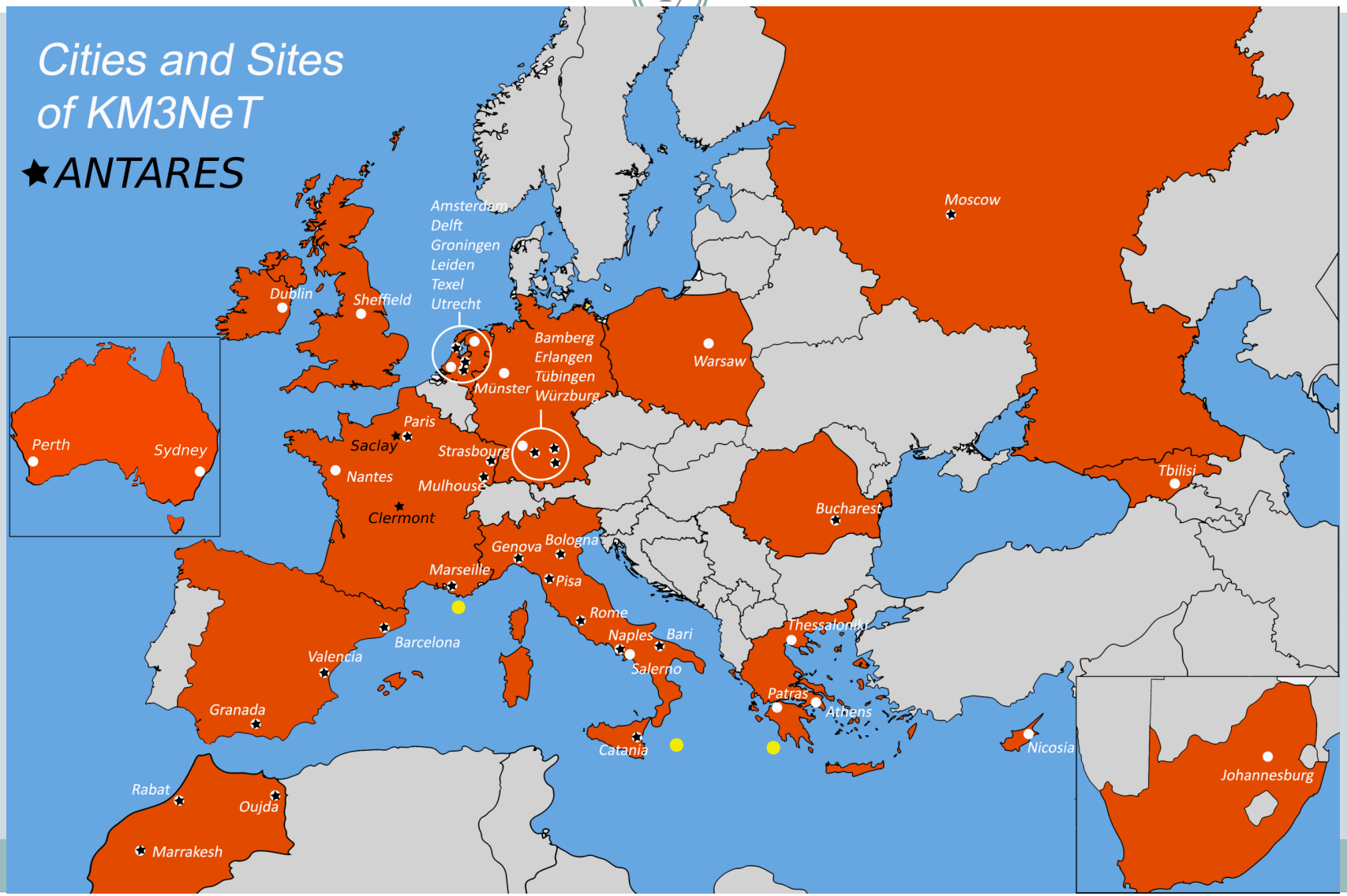
Detector layout



Phase 1 in KM3NeT-Italia:

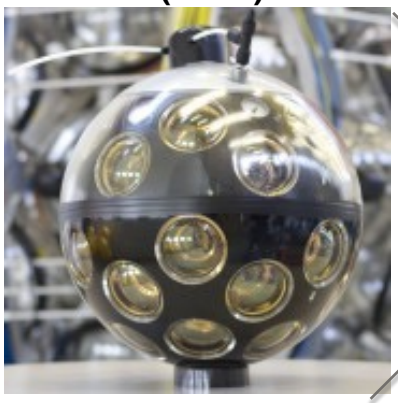
24 strings

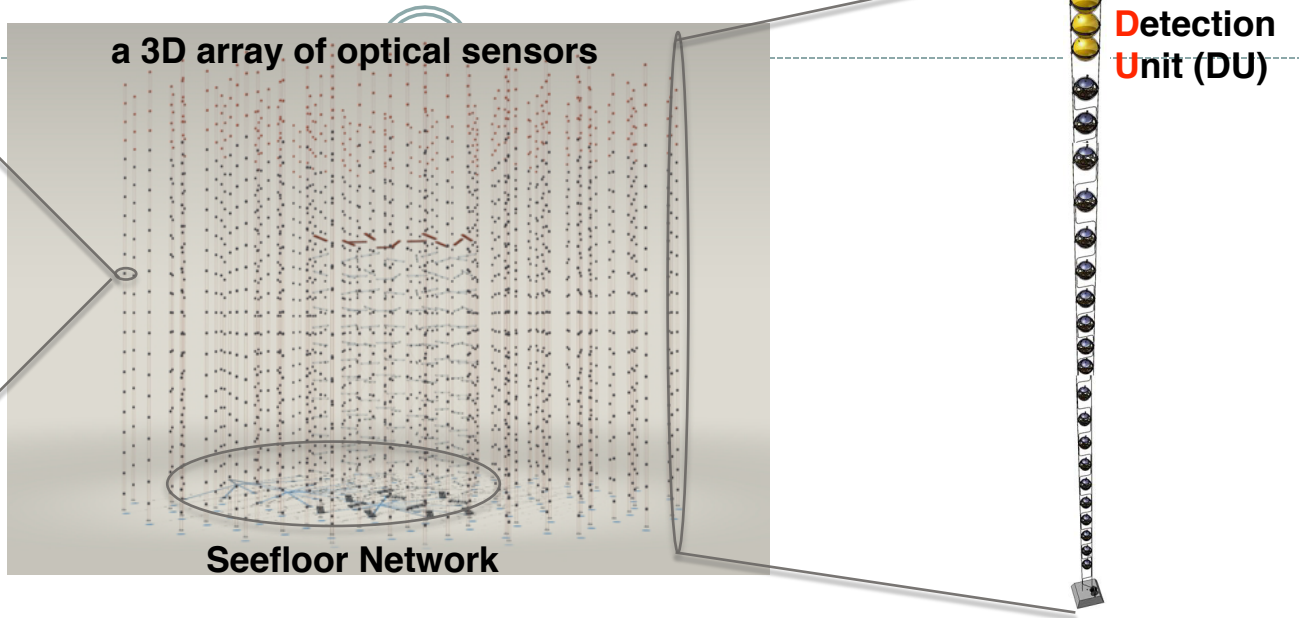
ANTARES & KM3NeT Collaborations



The KM3NeT design

The optical sensor: the Digital Optical Module (DOM)





- The ARCA detector is made of two building blocks of 115 Detection Units (DU) 90 m distant (0.5 km3/block)
- The DU is a vertical slender string equipped with 18 Digital Optical Modules (DOM) 36 m distant. Each DOM consists of 31 3" PMTs.
- Power and data distributed by a single backbone cable with breakouts at DOMs
- Sea network of submarine cables and Junction Boxes connected to shore via a main e/o cable
- All data to shore

Il Modulo Ottico Digitale (DOM)

~42 cm

Segmented cathode area: 31 x 3" PMTs

Light concentrator ring

Cathode area: ~ 3 x 10-inch PMT

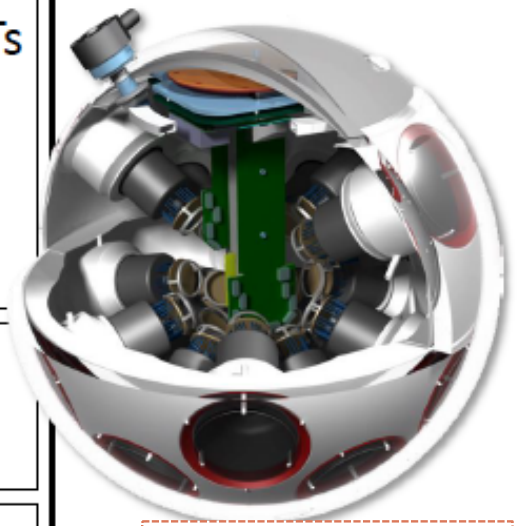
Custom low-power HV bases

LED & piezo inside

Compass and tiltmeter inside

PMT ToT measurements

FPGA readout, optical line terminator



↑ 12 PMTs
↓ 19 PMTs

~64 000 PMTs per Building Block!!

ETEL D792

Hamamatsu R12199

HZC XP53B20

The Digital Optical Module

31 x 3” PMTs
Active base & digital signal readout (ToT)
Light collection cone

1 AHRS (tilt, compass)
1 digital piezo receiver
1 LED emitter (time calibration)

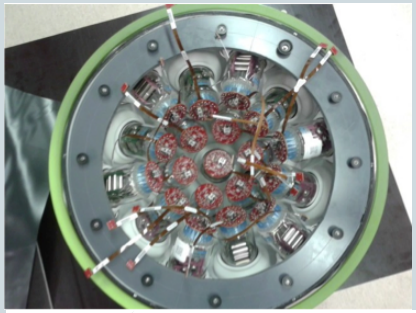
Central Logic Board (CLB)

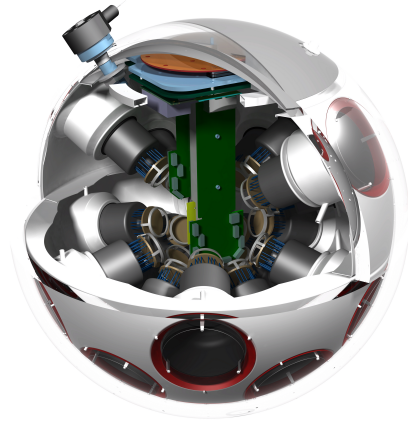
FPGA-based, White Rabbit (T_{GPS})

DWDM optical comm (1 color/DOM)

Power board

3d printed support structure
cooling structure (mushroom)
penetrator





La “Stringa” di KM3NeT

24 stringhe in installazione a Capo Passero

La prima stringa installata e connessa nel dicembre 2015

String-type with 18 optical modules

~36 m between optical modules

Lowest optical module ~100 m above seabed

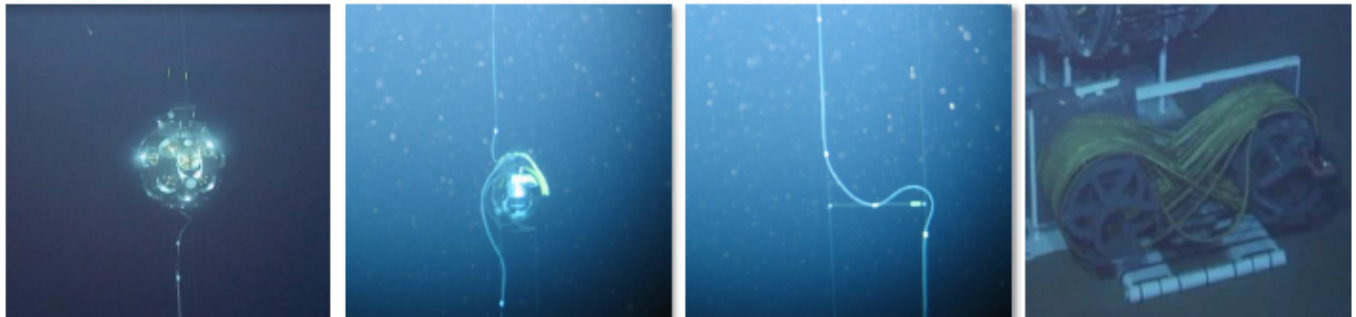
Two Dyneema® ropes

Backbone: 2 copper conductors; 18 fibres (+spares)

Break out of cable at each optical module

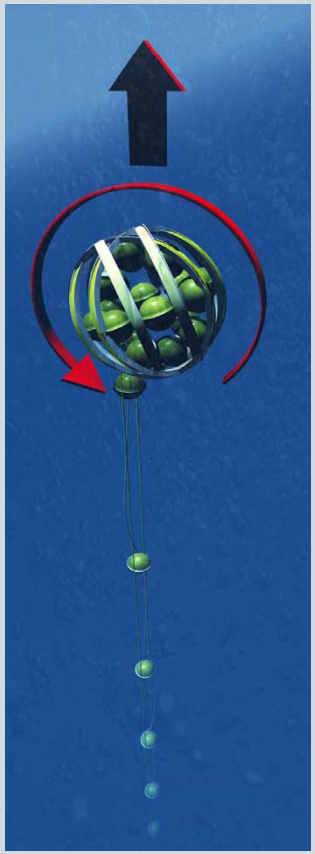
Base module with DWDM at anchor

Cable for connection to seafloor network

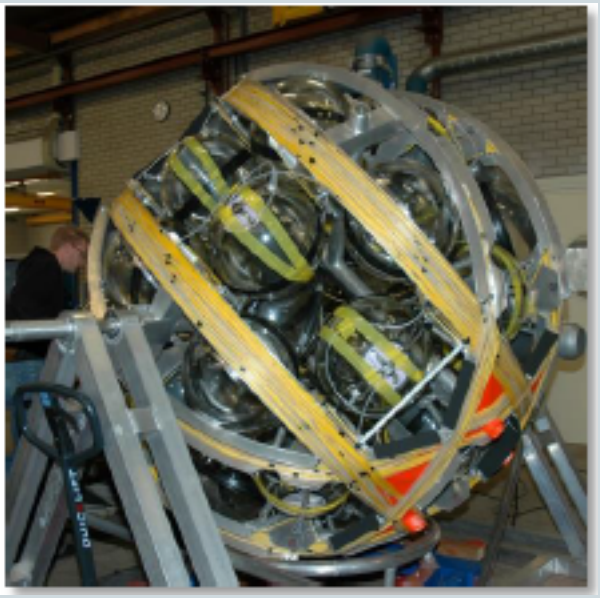


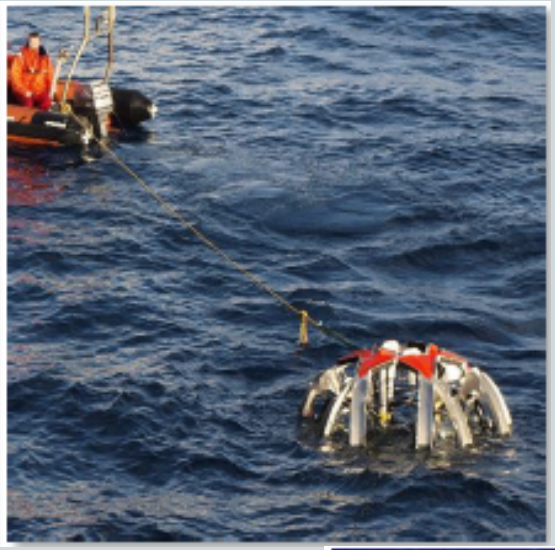
L’installazione della “Stringa”

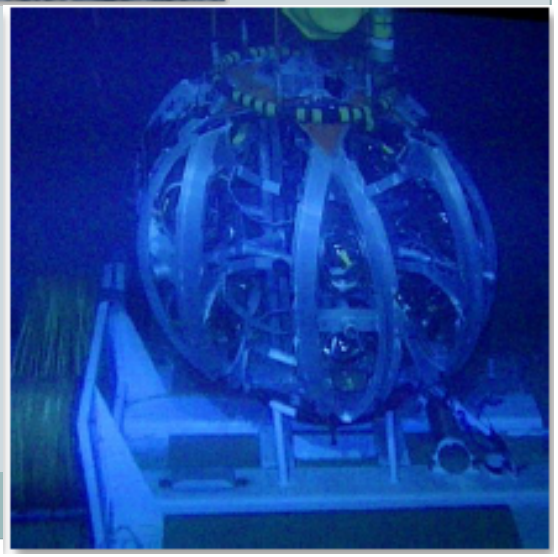
The Detection Unit deployment



Launcher vehicle



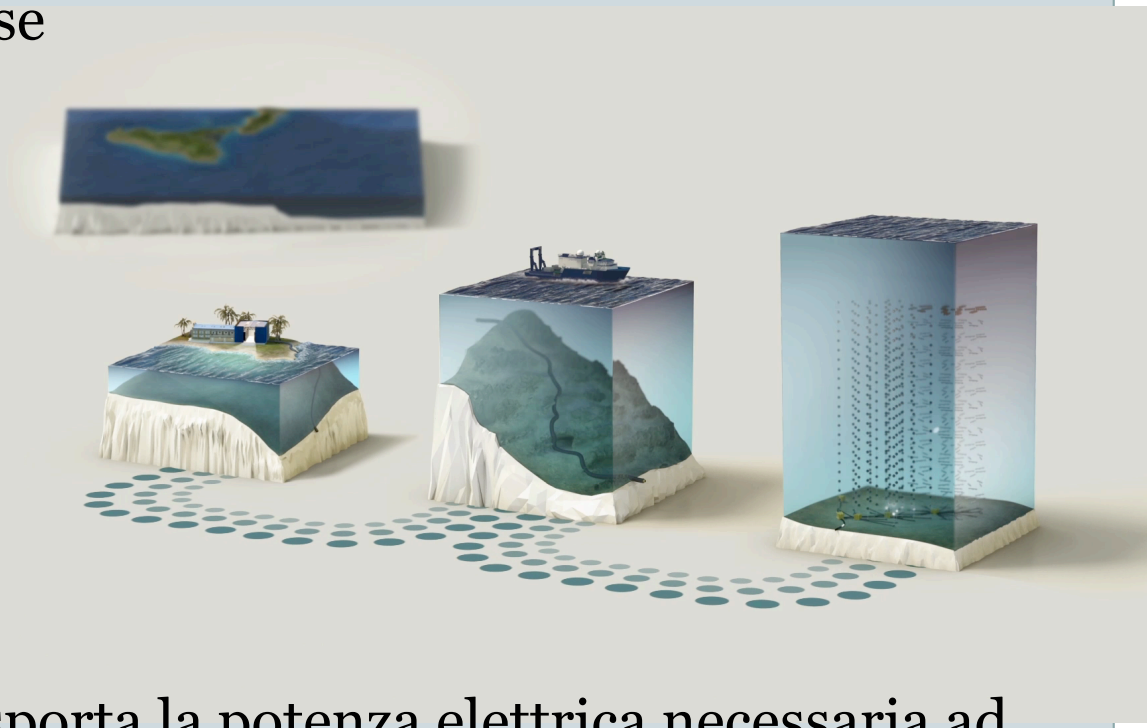




- rapid deployment
- autonomous unfurling
- recoverable

La rete di fondo

- Le stringhe sono connesse con delle cosiddette ‘Junction Box’ tramite opportuni cavi e connettori sottomarini.
- Le Junction Box a loro volta sono connesse con la terminazione del cavo elettro-ottico in mare.



- Il cavo elettro-ottico trasporta la potenza elettrica necessaria ad alimentare l’apparato.
- Un sistema di comunicazione a fibre ottiche permette di gestire i sensori sottomarini.

Underwater neutrino telescope

Main requests for a neutrino telescope:

- Time resolution < ns
- Spatial resolution ~ 10 cm
- Determination (as best as possible) of the deposited energy in the detector by charged secondary particles produced by neutrinos

Light velocity in sea water ~20cm/ns

- $\mathcal{O}$(500) optical module (phase-I)
- Modularity
- No off-shore trigger → All-data-to-shore concept

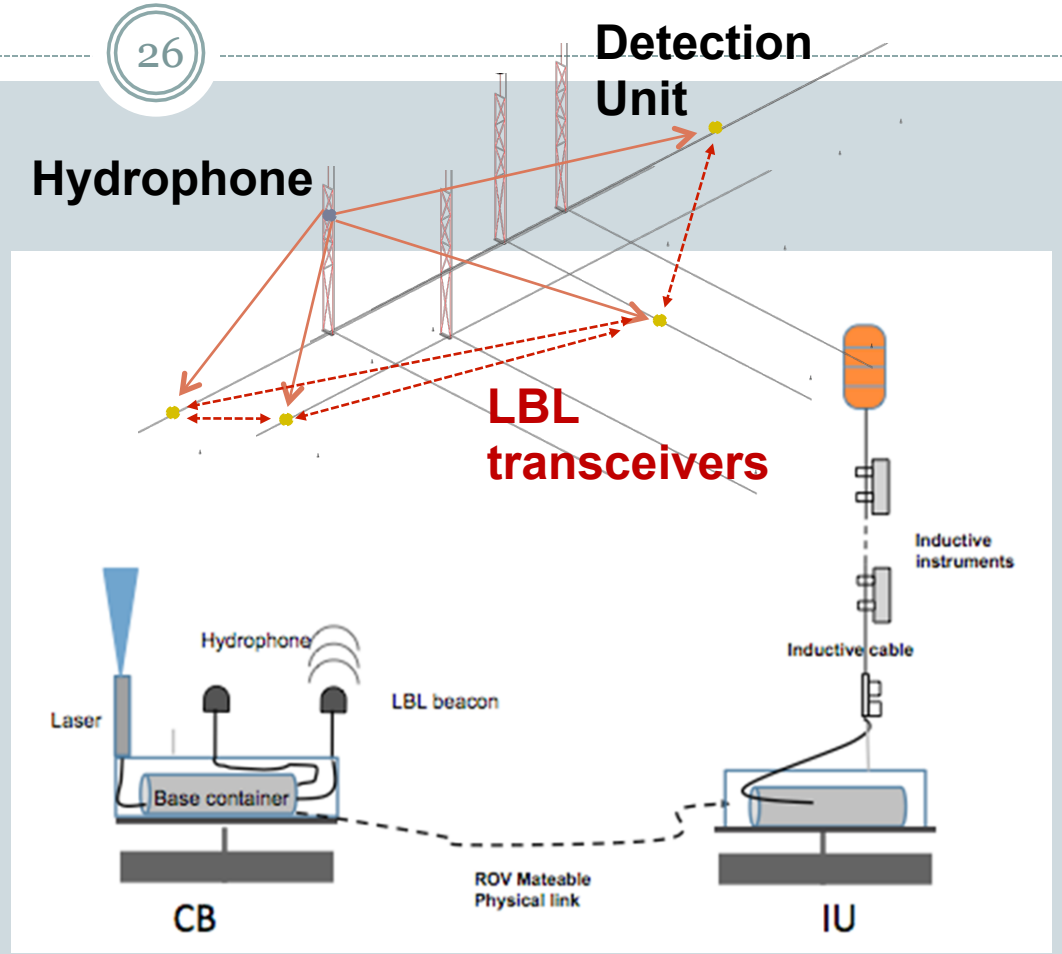
Detector Positioning

Digital piezo receiver
AHRS (compass, & tilt)

DOM

DU base

Hydrophone

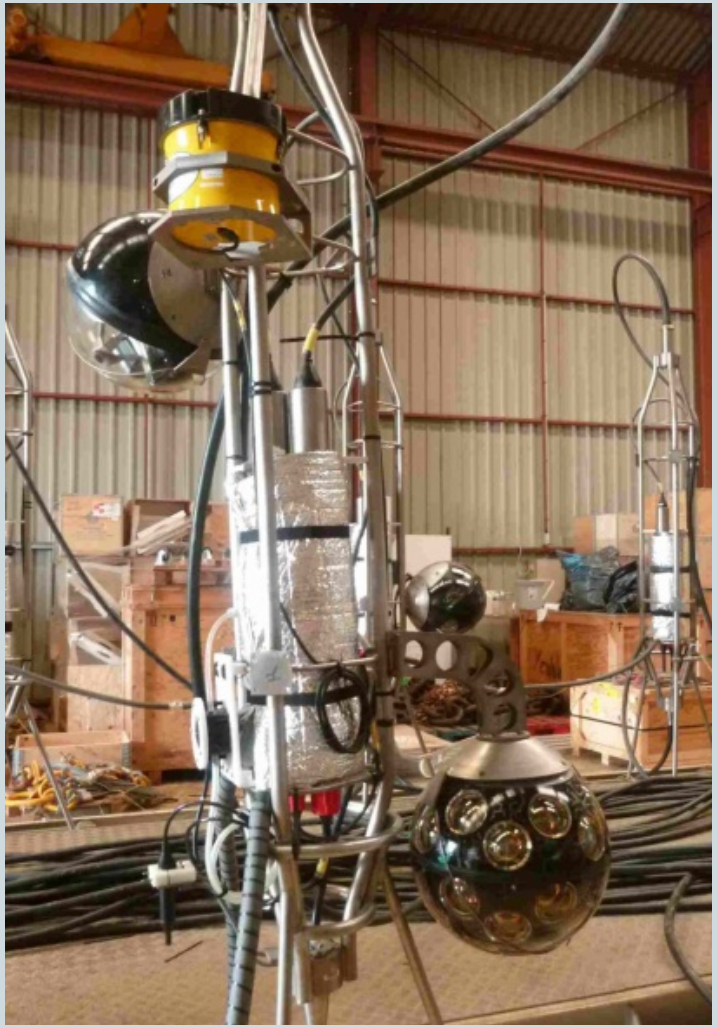


Calibration Base
Acoustic Long Base-Line
Laser Beacon (time calib)

Instrumentation Unit
Sea Currents
Sound Velocity

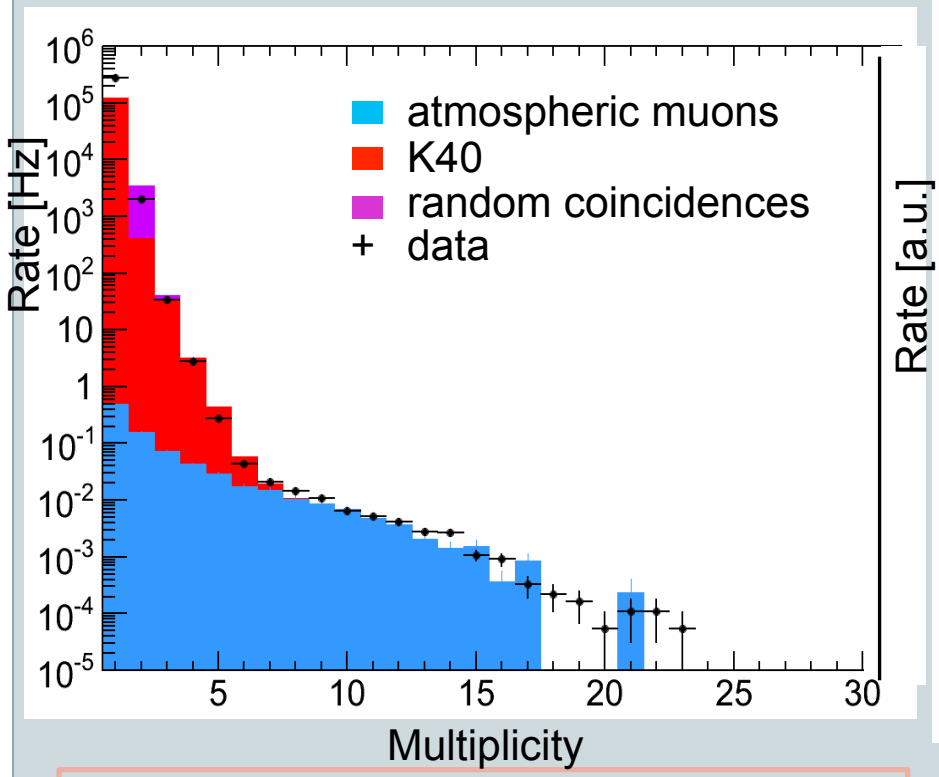
Prototype and Qualification Projects (1)

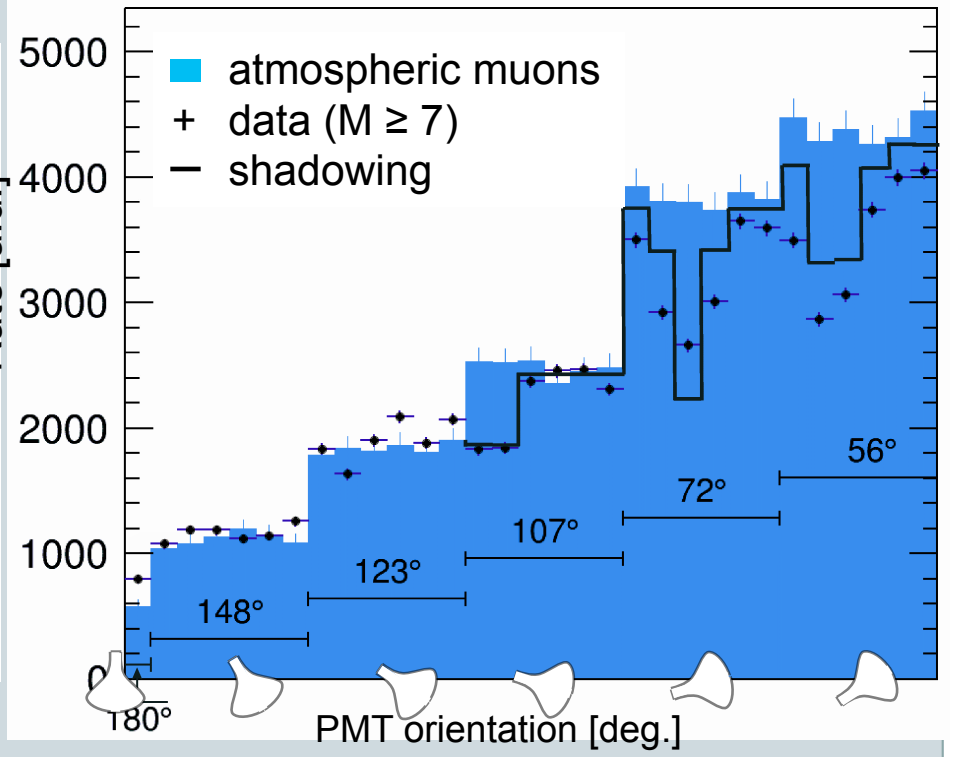
- Fully equipped DOM: 31 PMTs + acoustic positioning sensors + time calibration LED beacon mounted on the Instrumentation Line of ANTARES (2475 m deep)
- Deployed and connected with ROV on 16 April 2013
- PPM-DOM operational and working since installation → Validation of DOM technology



Results from prototype DOM

Published in Eur. Phys. J. C 74 (2014) 3056





Photon counting

- N_{coinc}>6 reduces ^{40}K contribution
- Single ^{40}K rate ⇒ 5kHz as expected

Directionality

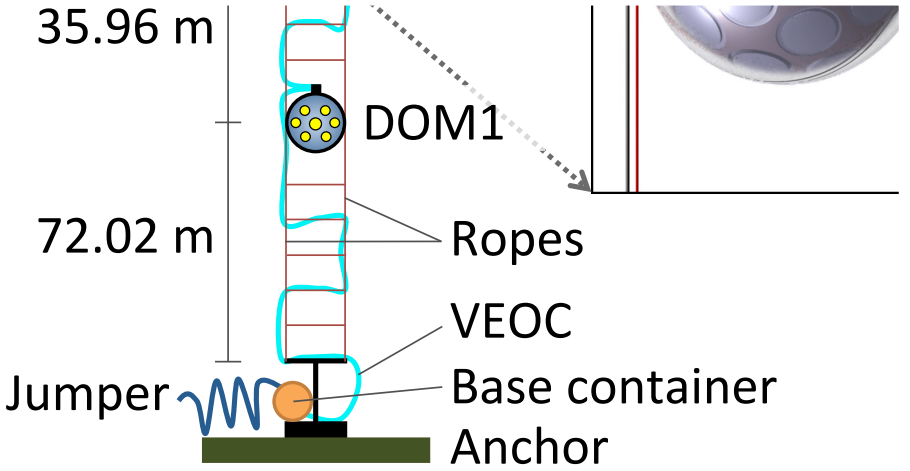
Upper PMTs see more events ⇒ directional information from single storey

Prototype and Qualification Projects (2)

- **Pre Production Model Detection Unit** (**PPM-DU**) deployed in the Capo Passero site, off-shore the Sicilian coast May 2014
- Main purposes:
  - 'Dry run' of marine operations — string deployment, submarine connection, unfurling procedure
  - Validate the DU structure
  - Operation and data handling tools
  - Test the software architecture developed for the km^3-scale detector
  - Improve our knowledge of the site (bioluminescence)
- Great interest to have results for a publication soon!

Detection Unit prototype

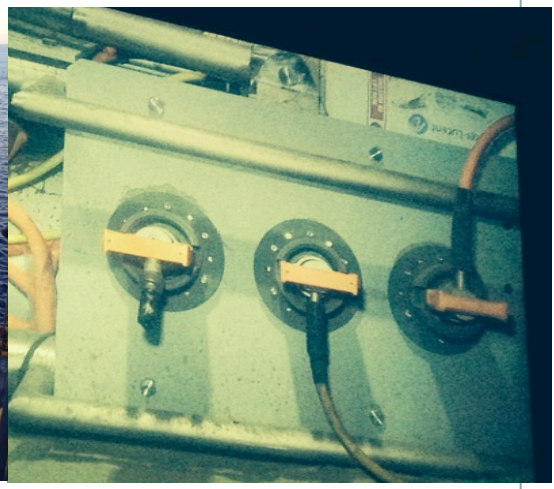
- 2 DOMs with ETEL D783FLA PMTs
- 1 DOM with Hamamatsu R12199-02 PMTs
- LED nanobeacon and piezo
- Deployed at the KM3NeT-It site at 3500m depth, 100 km off shore
- Operational in May 2014 – July 2015



DU prototype integration and deployment

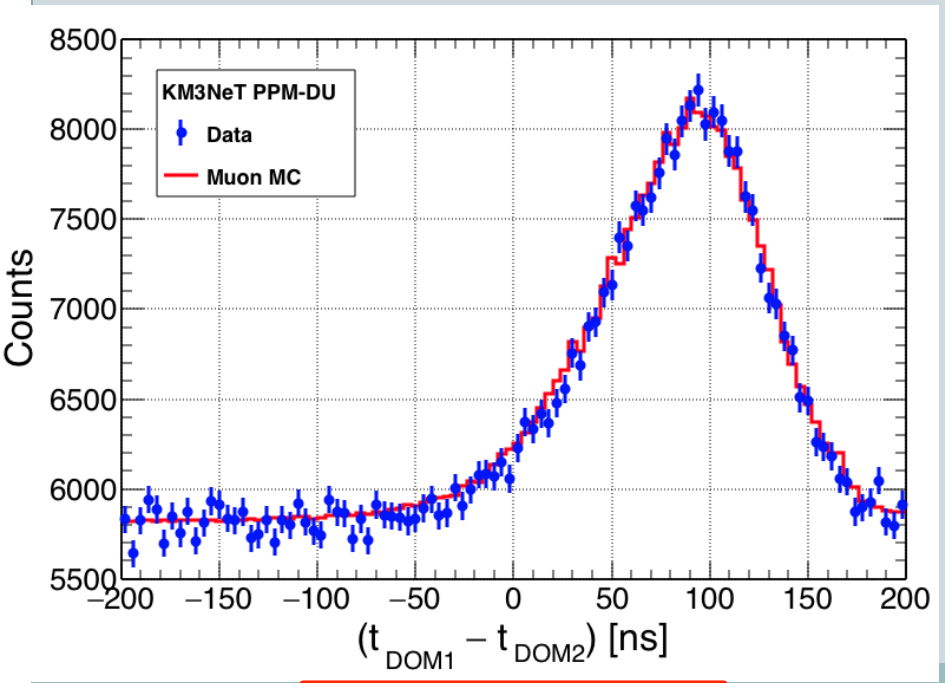
Integrated at Nikhef (Amsterdam) and CPPM (Marseille)

Deployed at 3500 m depth at the site of Capo Passero (KM3NeT-It) in May 2014

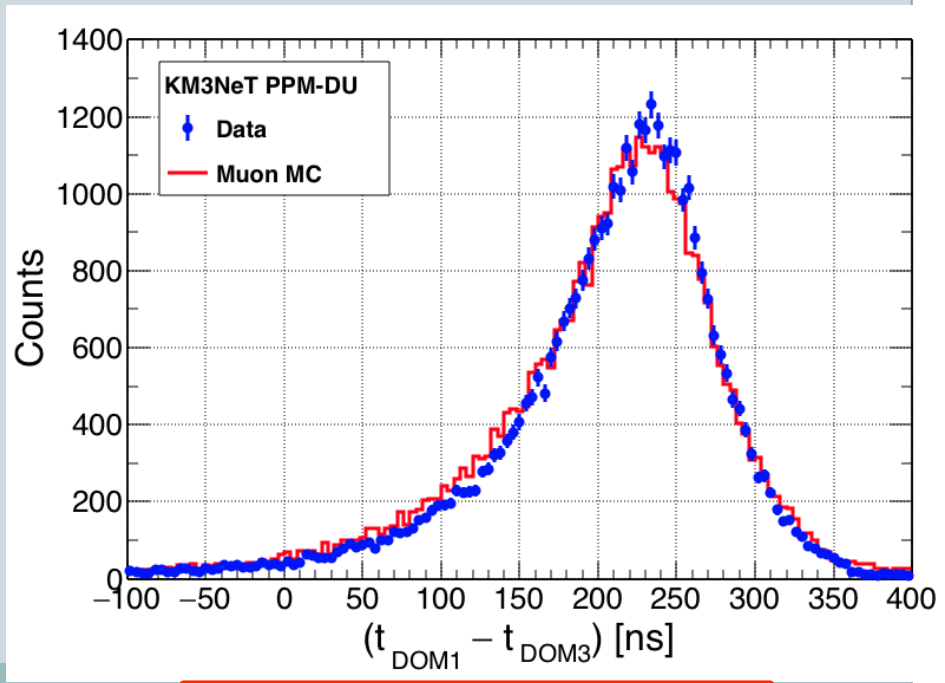


Inter-DOM time calibration

- K-40 decay in sea water to calibrate Intra-DOM time offsets using local coincidences
- LED nanobeacons to calibrate Inter-DOM
- Atmospheric muons can be used to calibrate in time DOMs: very good agreement with MC simulations

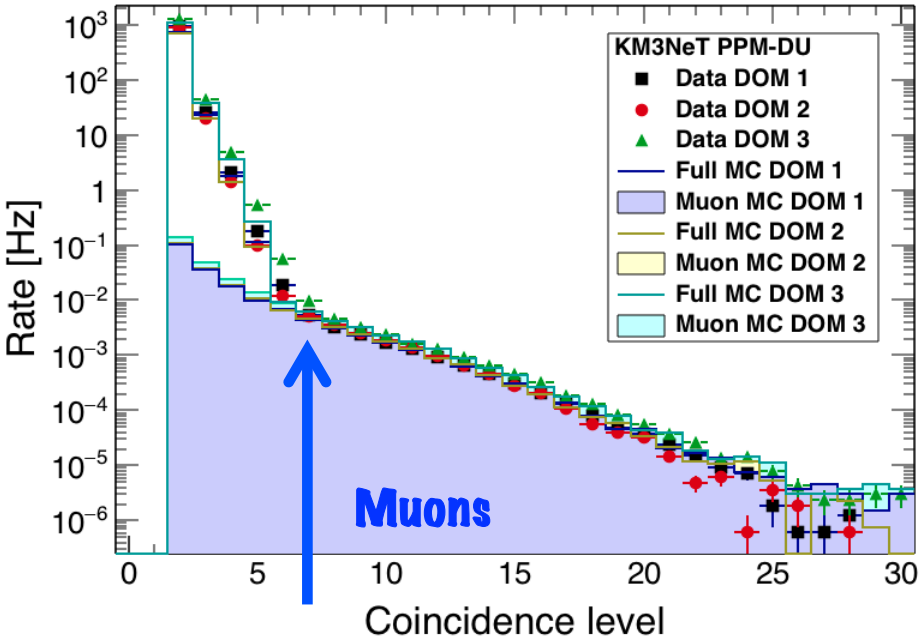


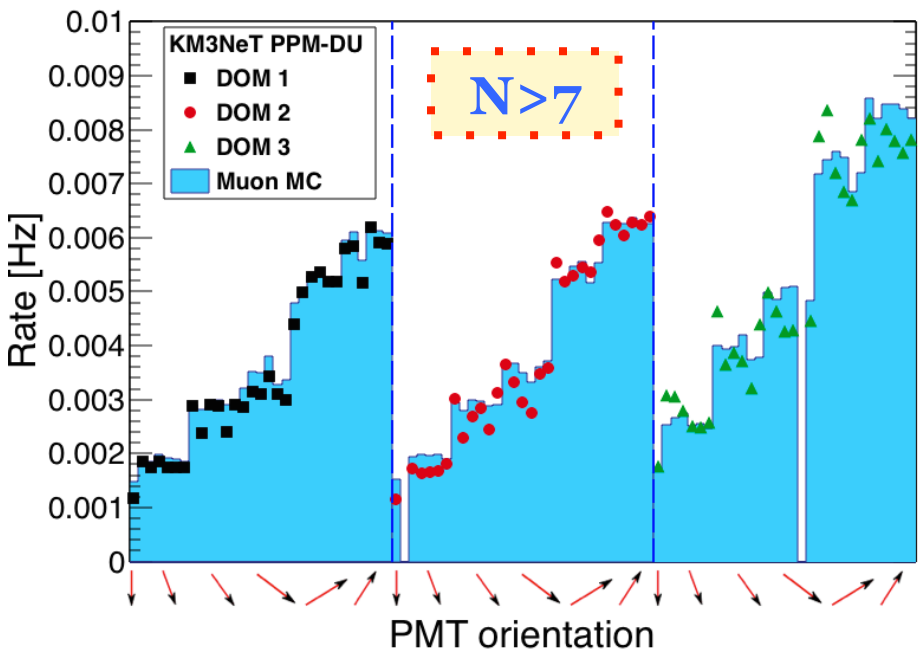
DOM1+DOM2



DOM1+DOM2+DOM3

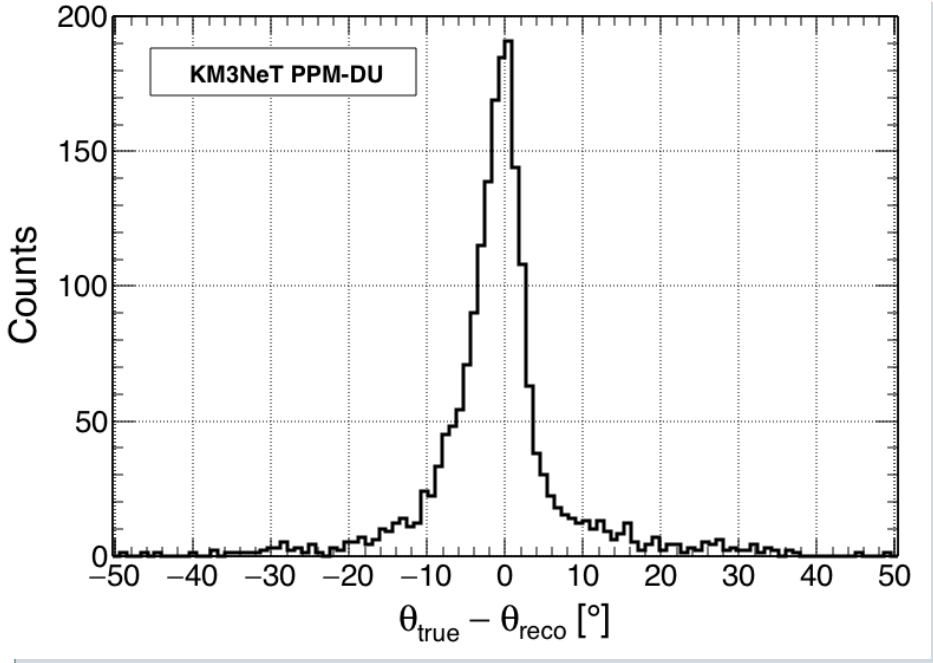
PPM-DU: Searching for muons

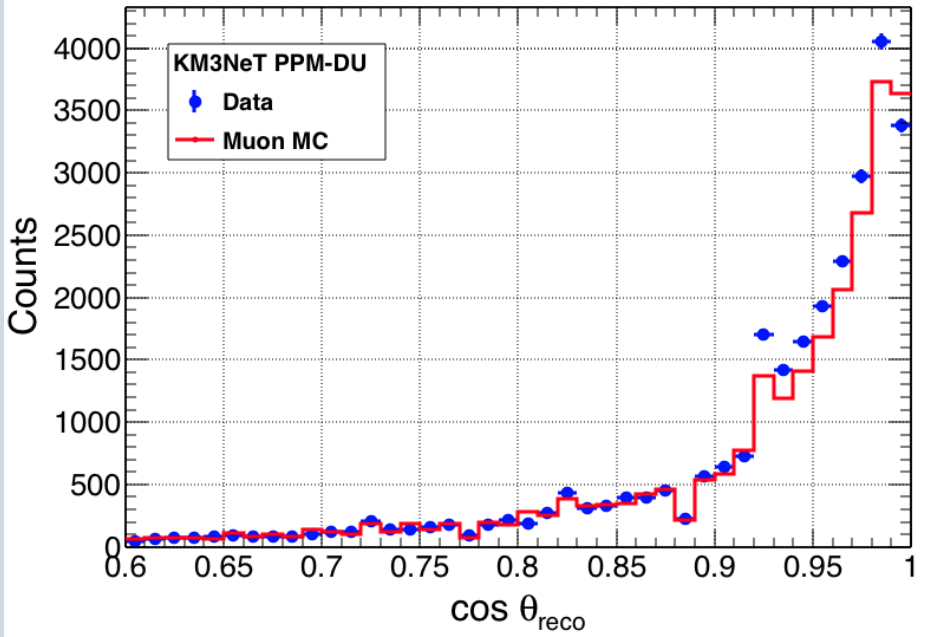




- L1 trigger = coincidence between two PMTs in 25ns; unique PMTs are selected inside the DOMs in a 130 ns time window
- The change of shape shows the region in which muons become to be dominant over the optical background
- Directionality of the DOM → peculiar up/down shape

Zenith angle reconstruction



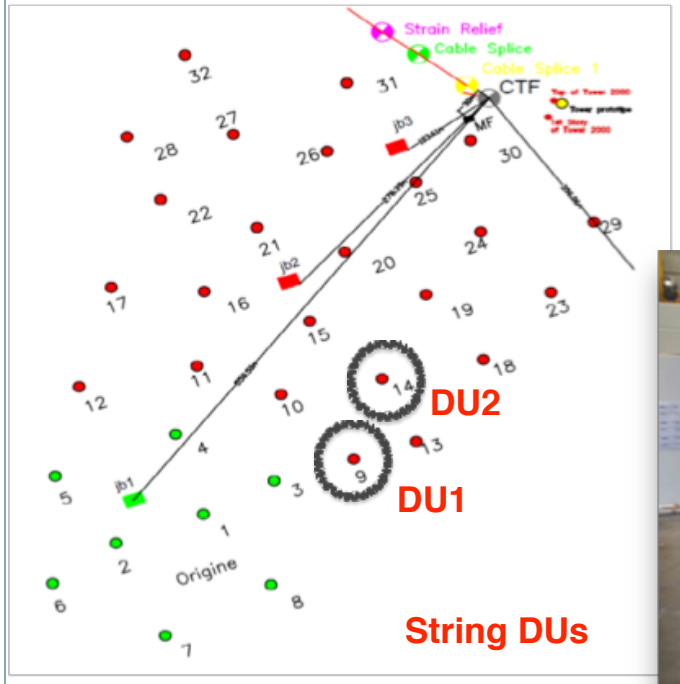


- Reconstruction of zenith angle of atmospheric muons
- Inputs: position of the three DOMs and time of the local coincidences
- FWHM = 7.6 degree zenith angular resolution achieved

KM3NeT-Phase1: the first DUs installed

Two detection units in operation at Capo Passero site: the first deployed in December 2015, the second one in May 2016.
A third DU recovered for inspection in July 2016.

ARCA phase-1 footprint

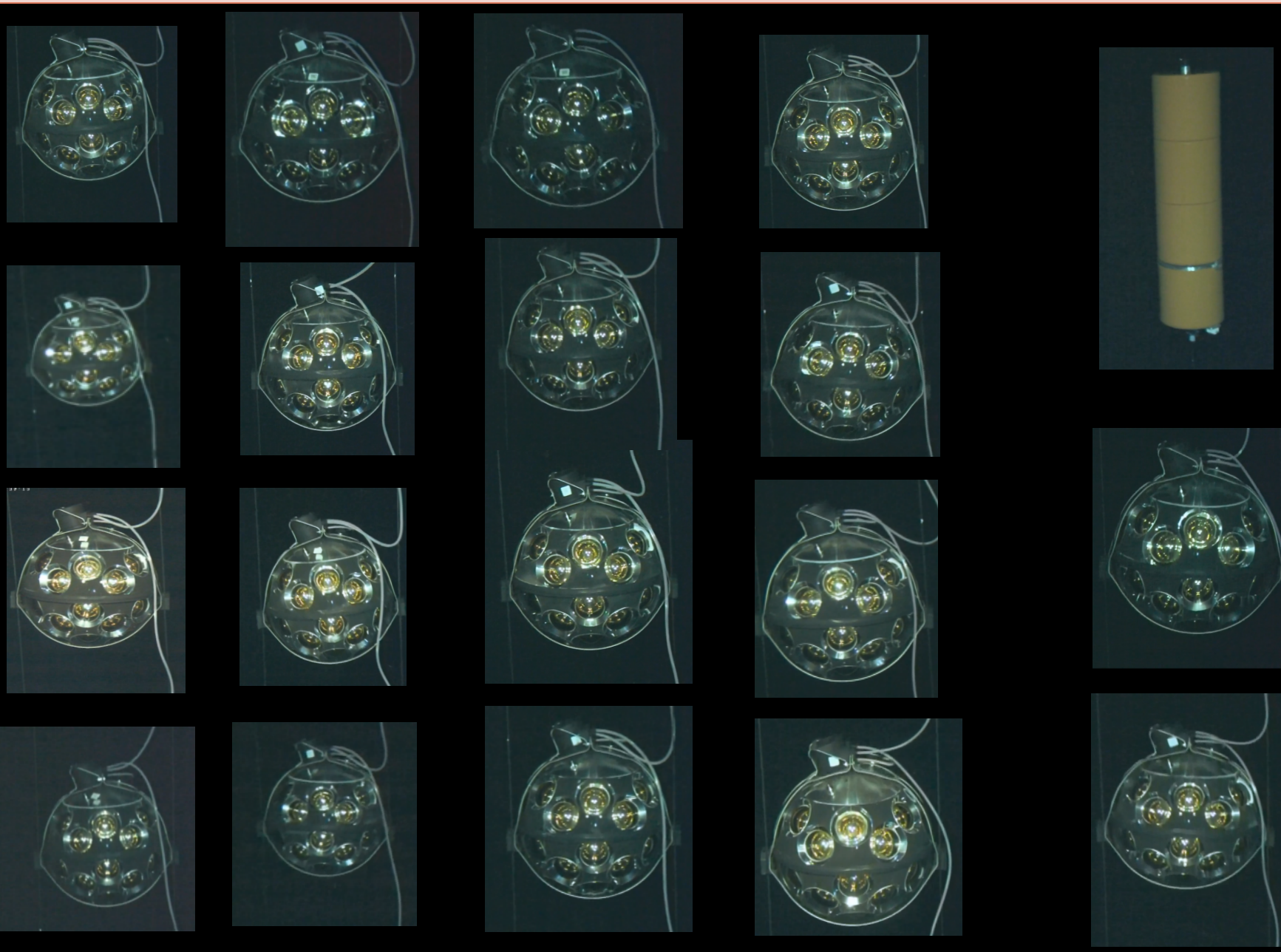


CTF

Capo Passero shore station

ARCA DU1 at the sea bottom

The first KM3NeT String (in-situ)



40K: Inter-PMT Calibration

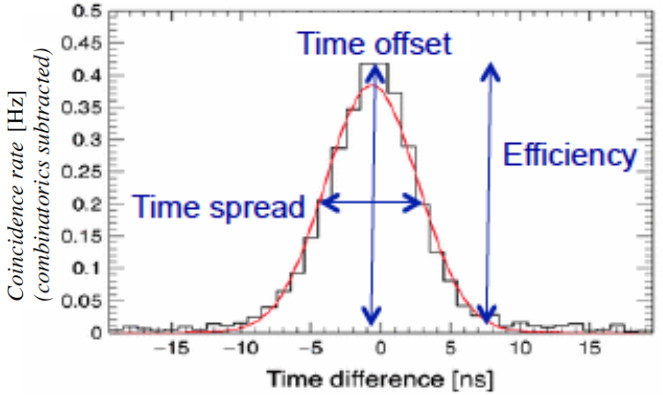
^{40}K

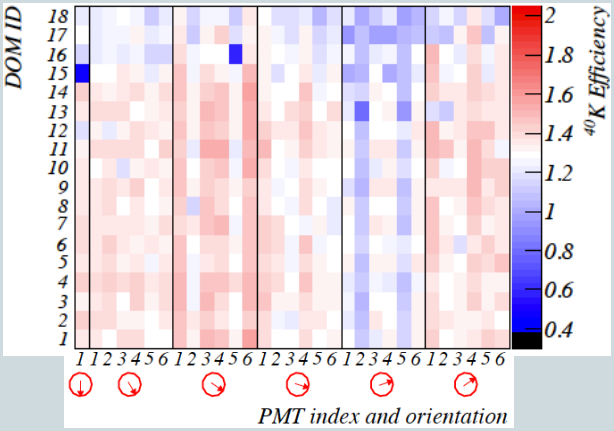
e^- (β decay)

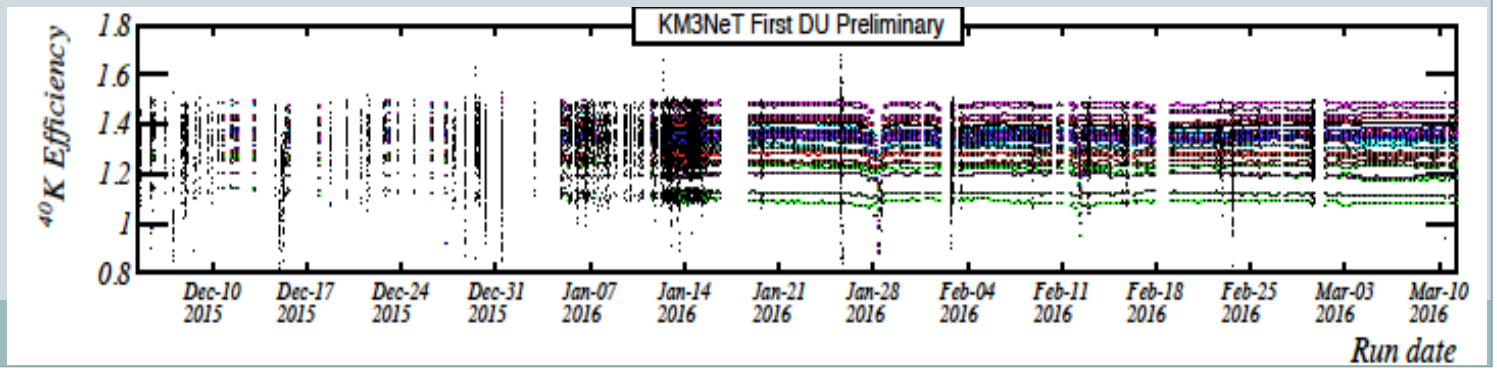
^{40}Ca

Up to 150 Cherenkov photons per decay; stable ^{40}K concentration

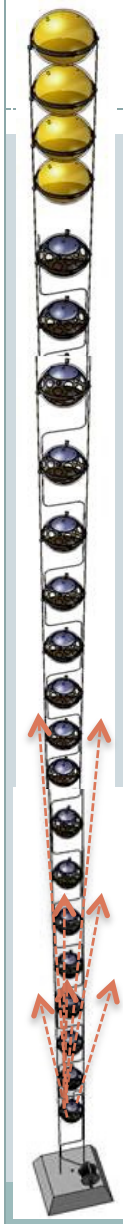
- Time calibration
- Relative PMT efficiency

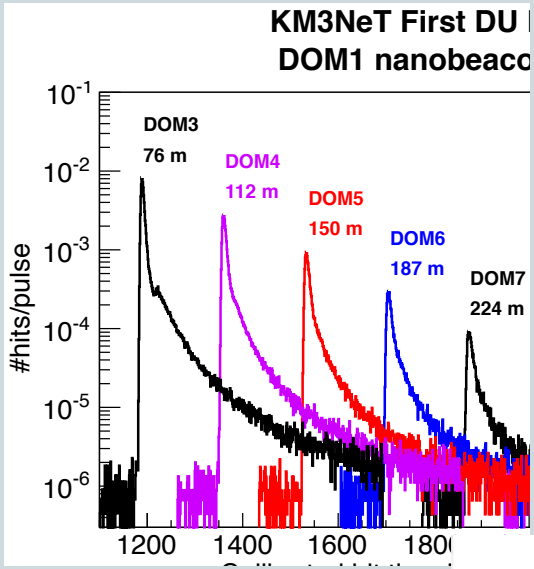


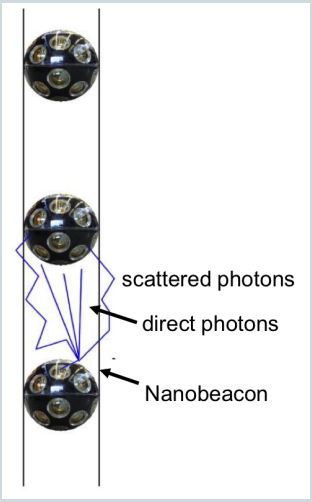


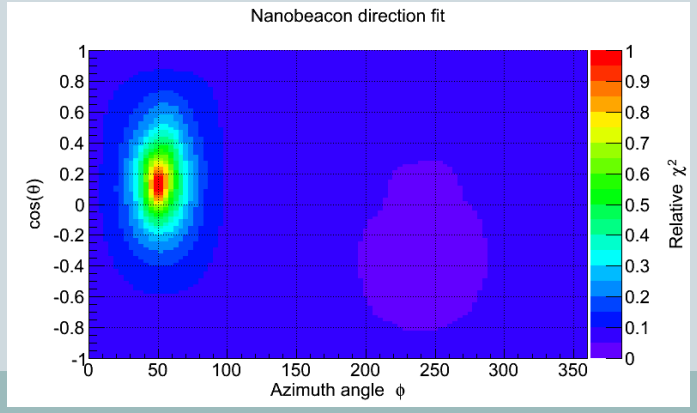


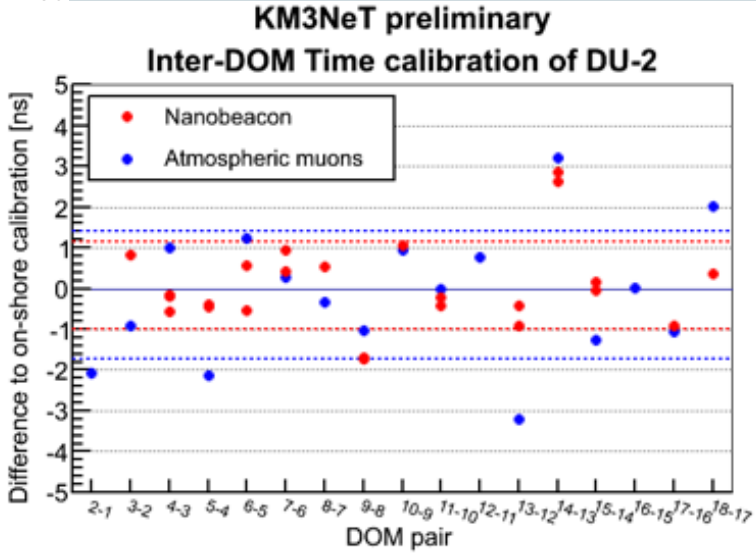
Nanobeacon: Inter-DOM Calibration



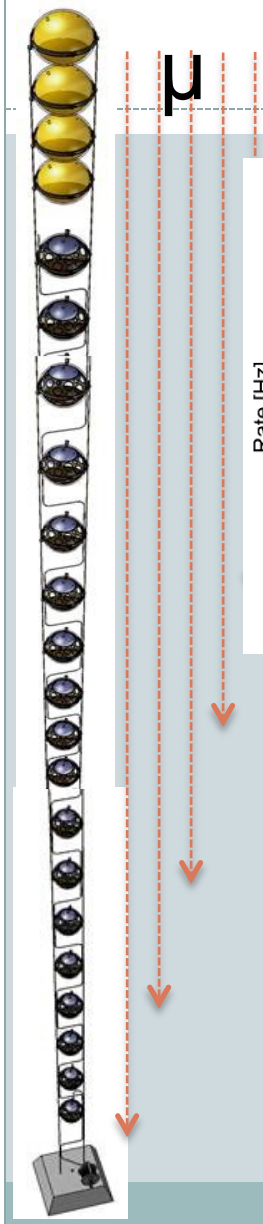


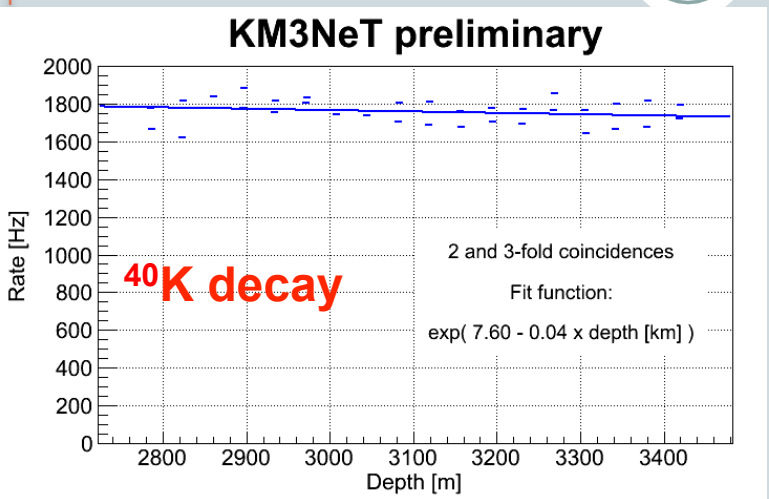


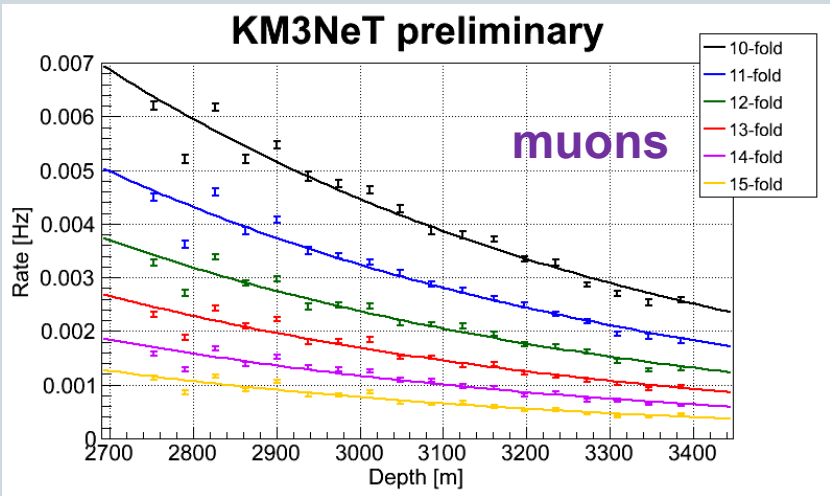


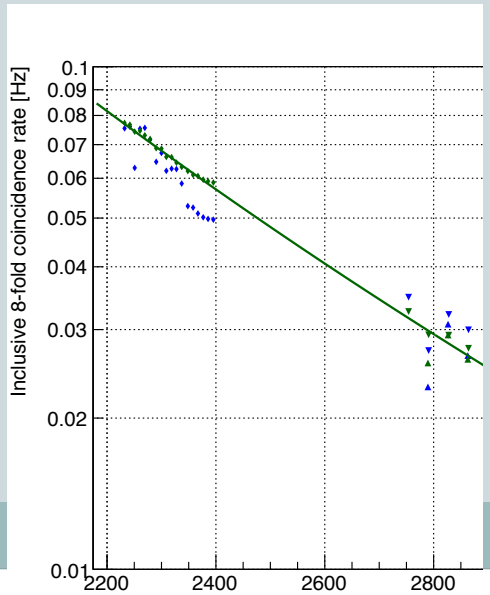


Muon Depth Dependence









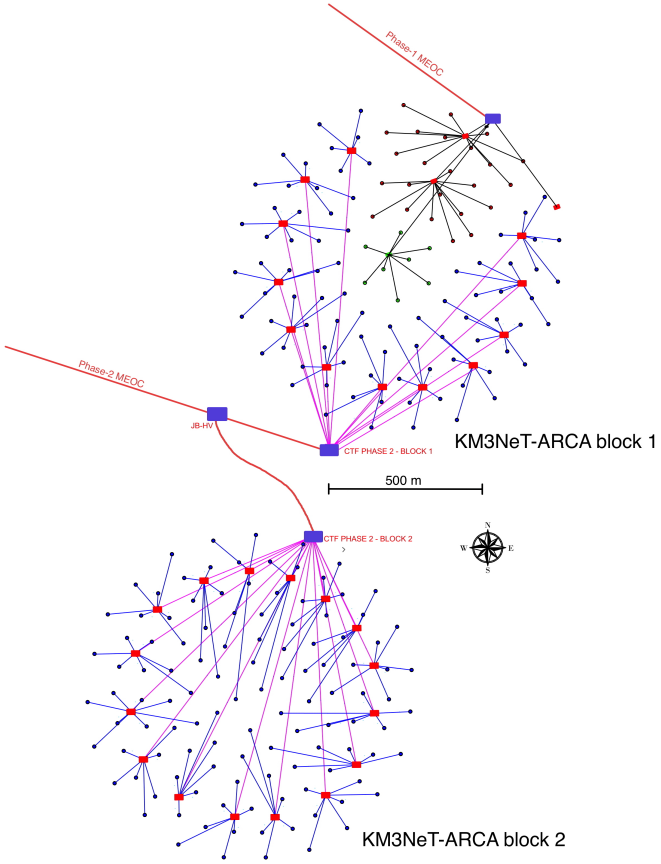
Dati di ARCA + ORCA

Misura indiretta del flusso di muoni atmosferici

The KM3NeT-ARCA layout

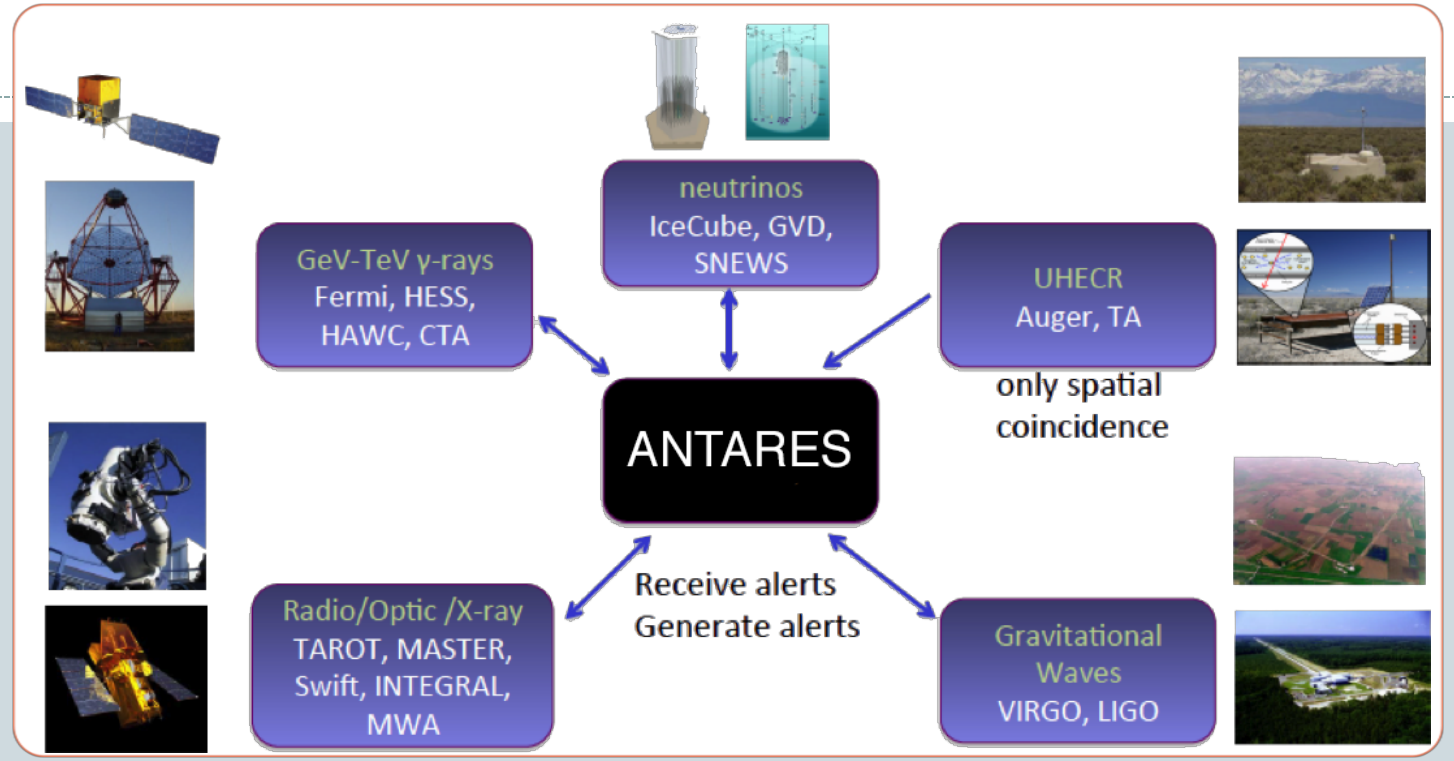
- KM3NeT-ARCA: two building blocks of 115 DUs (~1 km^3)
  - 18 DOM per DU
  - Vertical DOM spacing 36 m
  - Inter-DU spacing 90 m

- Next slides show the main results obtained from MC simulations using the analysis tools developed by the collaboration



Detector layout

Multimessenger searches



* participation to AMON
Astrophysical Multimessenger Observatory Network

+SNEWS for low E_ν:
receiving alerts for ANTARES
sending with KM3NeT

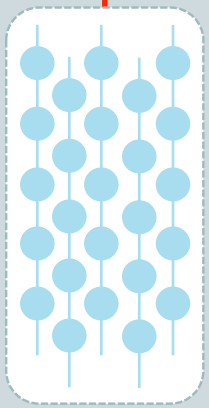
Asterics
Astronomy ESFRI & Research Infrastructure Cluster

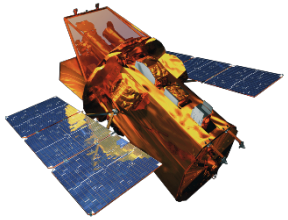
Bringing together the astronomy, astrophysics and particle astrophysics communities.

Astropart. Phys. 35, 530 (2012) and JCAP 02, 062 (2016)

ANTARES: Real-time neutrino alerts

Real-time analysis → Alert triggering





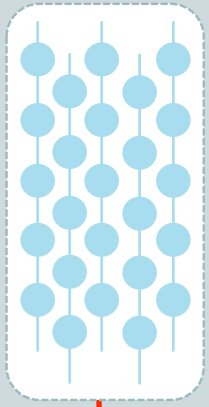
+ …

Performances:

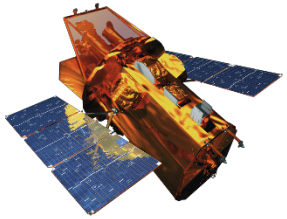
- Time to send an alert: ~5 s
- Median angular resolution: 0.5°

ANTARES: External alerts follow up

Offline studies
- Calibrated geometry
- Calibrations
- More refined tracking



Online alert



+ …

Prompt search
- Online tracking
- Default geometry
- Prompt response (minutes)
- (Lower trigger threshold)