Status and perspectives of the KM3NeT

Annarita Margiotta
Dip. di Fisica e Astronomia UniBO and Sezione INFN – Bologna
on behalf of the KM3NeT Collaboration

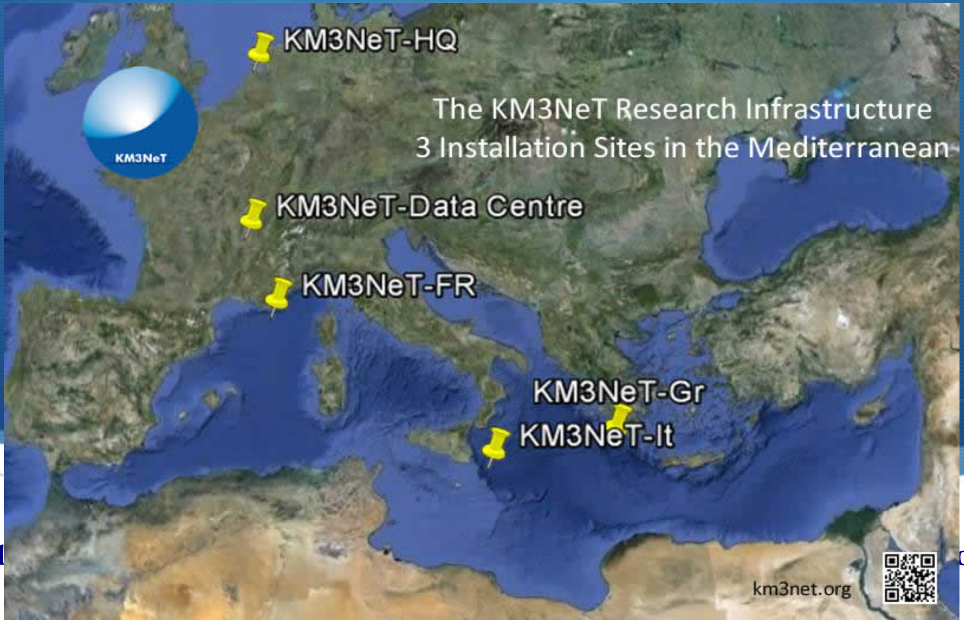
INFN
Istituto Nazionale di Fisica Nucleare
Sezione di Bologna

KM3NeT

ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA
A.D. 1088

What is KM3NeT?

- Distributed research infrastructure
- Network of neutrino telescopes:
  - exploration of the whole neutrino energy range
- ARCA: Astrophysical Research with Cosmics in the Abyss
  - Study astrophysical neutrino fluxes at E > 100 GeV (@KM3NeT-It)
- ORCA: Oscillations Research with Cosmics in the Abyss
  - Resolve the neutrino mass hierarchy - 1 GeV < E < 100 GeV (@KM3NeT-Fr)



Scientific goals of KM3NeT

ARCA

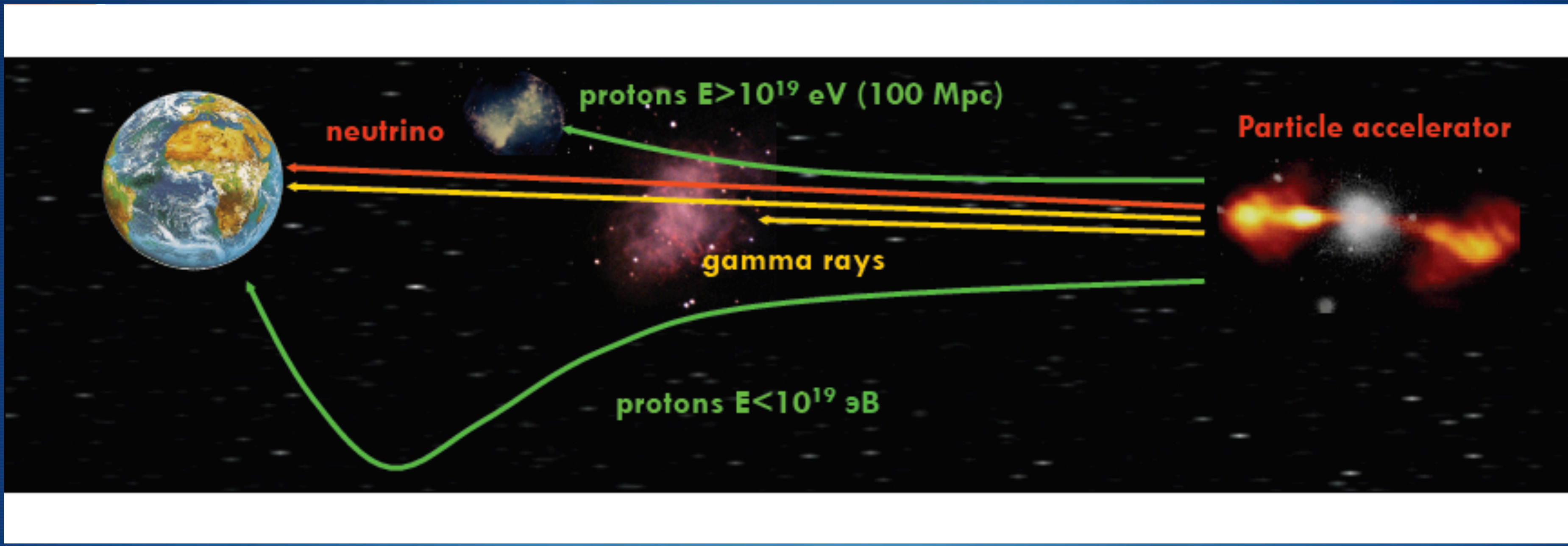
- Point sources identification: galactic TeV gamma sources
- Diffuse high-energy neutrino fluxes → IceCube flux

ORCA

- Neutrino-mass hierarchy studies
- Atmospheric neutrino oscillations

This talk is dedicated mainly to ARCA

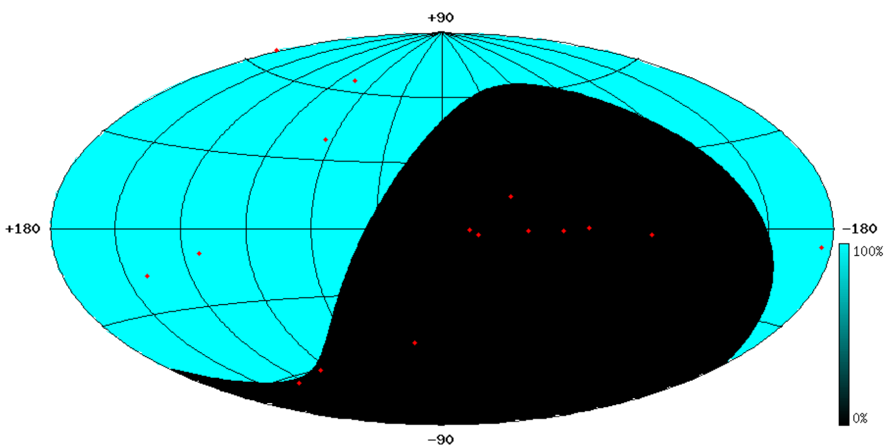
Why a HE neutrino telescope in the Mediterranean Sea



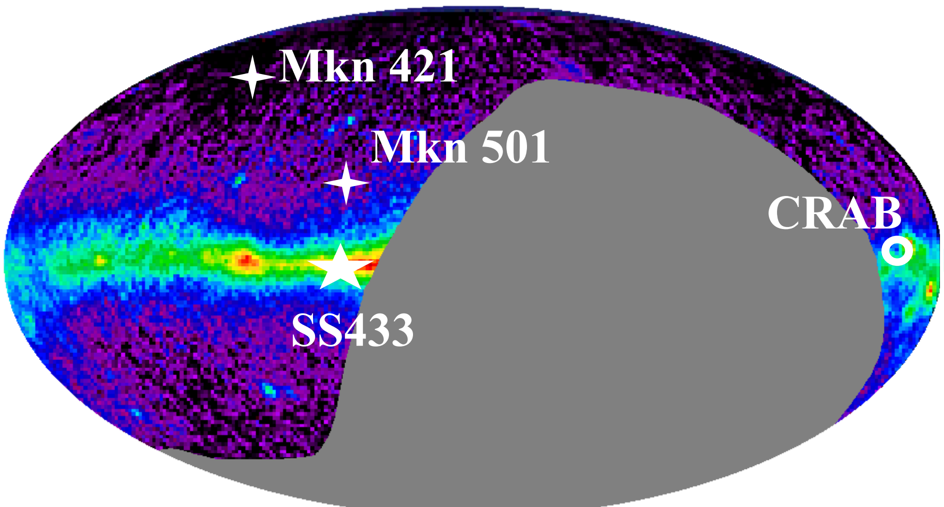
- VHE γ rays absorbed by dust and radiation
- Ambiguous information about leptonic vs hadronic mechanisms
- Charged CRs direction scrambled by magnetic fields

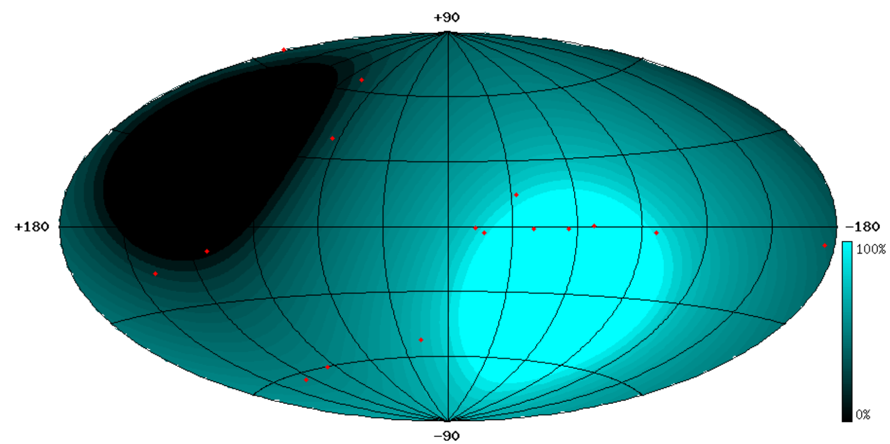
Northern vs Southern neutrino telescope

- Favourable location to observe directly the Southern Sky
- Excellent angular resolution thanks to the long scattering length

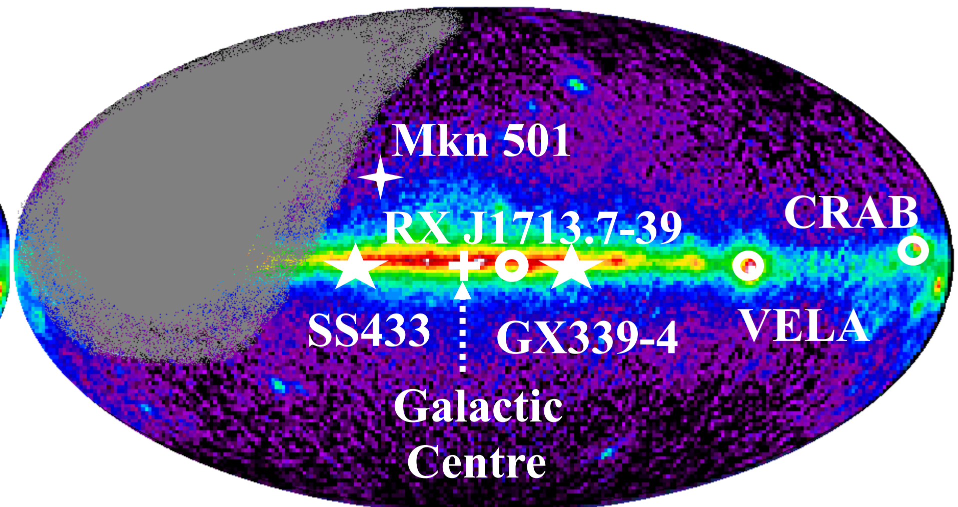


South Pole FoV

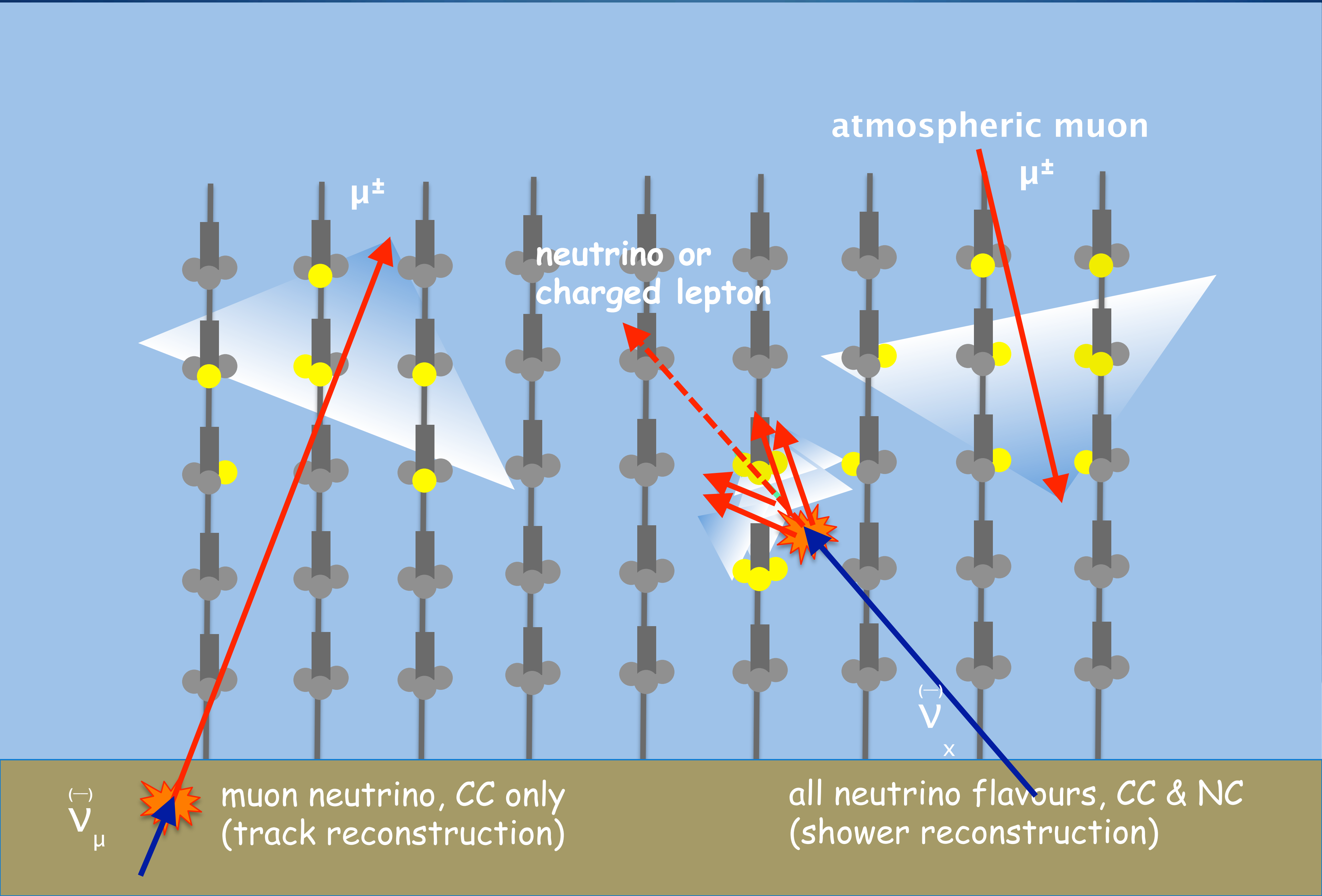




Mediterranean Sea FoV



How does a neutrino telescope work?

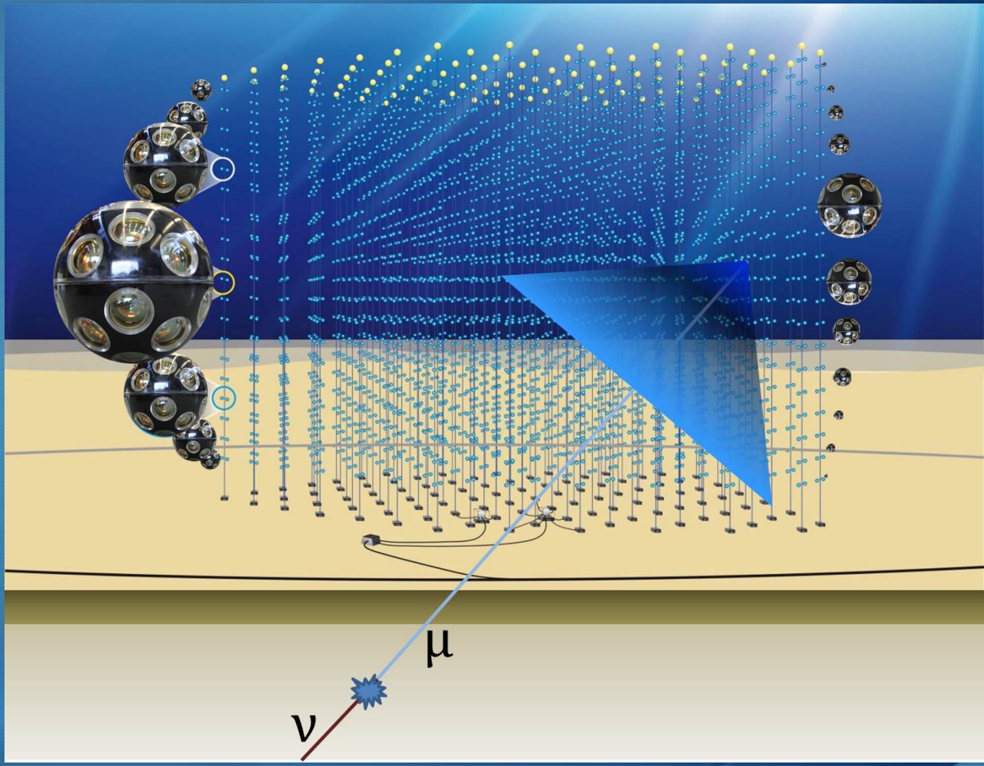


The KM3NeT design

- Detection unit (DU) = vertical string with multi-PMT digital optical modules (DOMs)
- Multi-site infrastructure
  - High energy:ARCA @ KM3NeT-It site
  - Low energy: ORCA @ KM3NeT-Fr site

Same technology

- Power and data distributed by a single backbone cable with breakouts at DOMs and optical data transmission
- Distance between DOMs **optimized** according to the energy range



Building block = 115 DUs

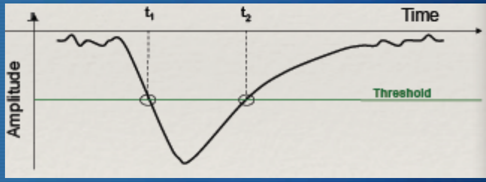
The Digital Optical Module

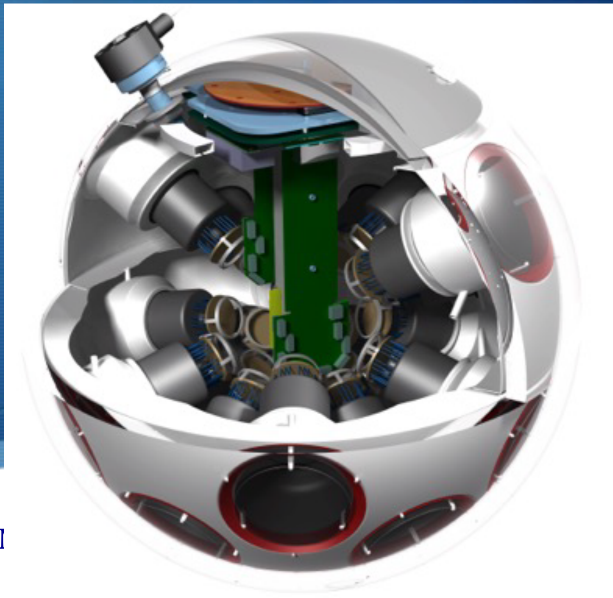
17”

Pressure resistant glass sphere

Innovative design

- 31 x 3” PMTs = 3 x 10” PMTs (photocathode area)
- 19 PMTs down looking/12 PMTs up looking
- Low power consumption < 10 W/DOM
- FPGA readout for each PMT
  - sub-ns time stamping
  - time over threshold (ToT)
- Calibration
  - LED & acoustic piezo



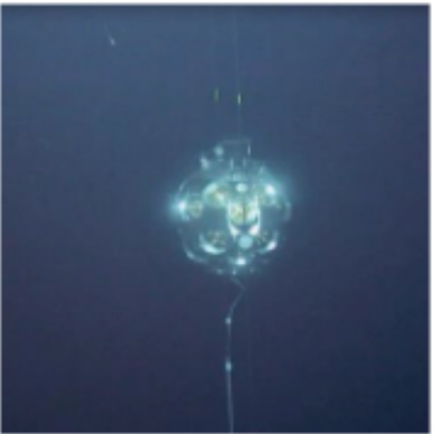


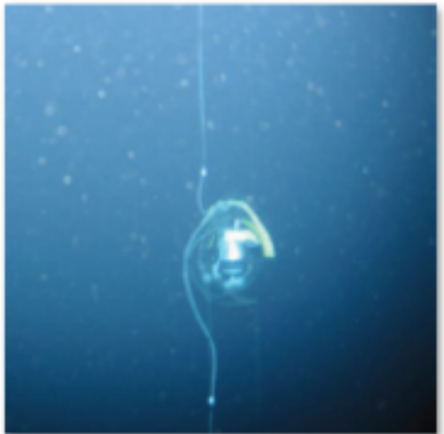
The Detection Unit

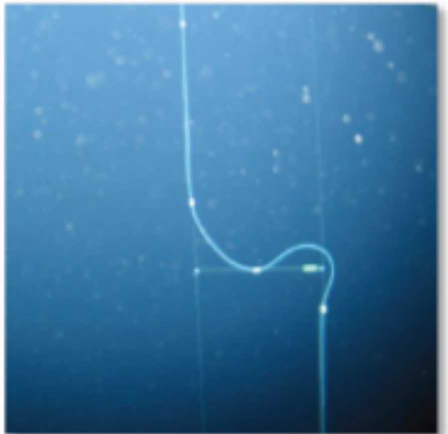
- Vertical string with 18 DOMs

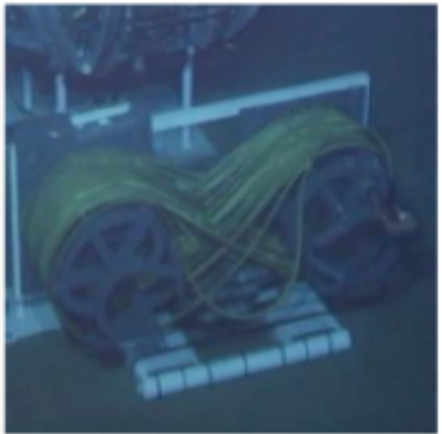
  (~ 700 m high for ARCA, still under study for ORCA)

- Mechanical structure:
  - two Dyneema® ropes
  - anchor and buoys to keep taut the string
- Backbone (VEOC): oil filled tube (~6mm diameter) with 2 copper conductors and 18 fibres; break out of cable at each DOM
- Base module with opto-electronics (DWDM) for data transmissionInterlink cables for connection to the sea floor network









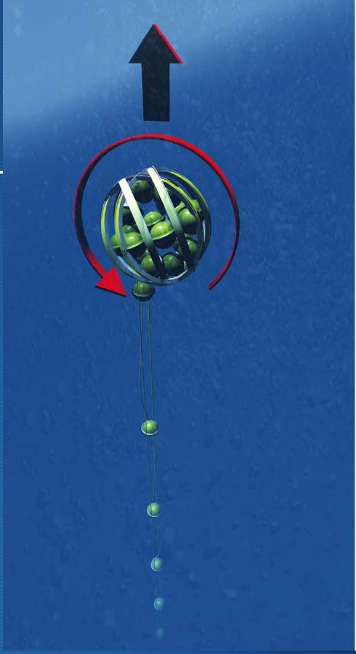
The Launcher of Optical Modules (LOM)

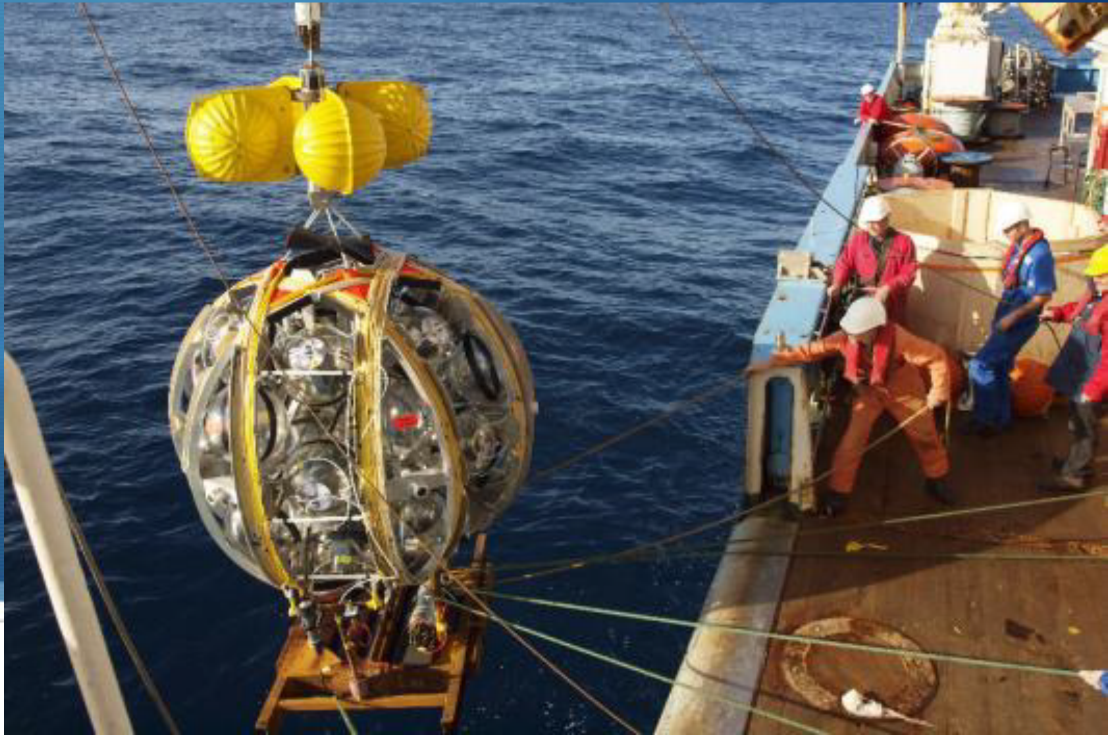
April 2013 - June 2014 : mechanical tests

Successful demonstration of deployment concept and of the functionality of the VEOC cable

diameter ~ 2 meters

- rapid deployment
- autonomous unfurling
- recoverable

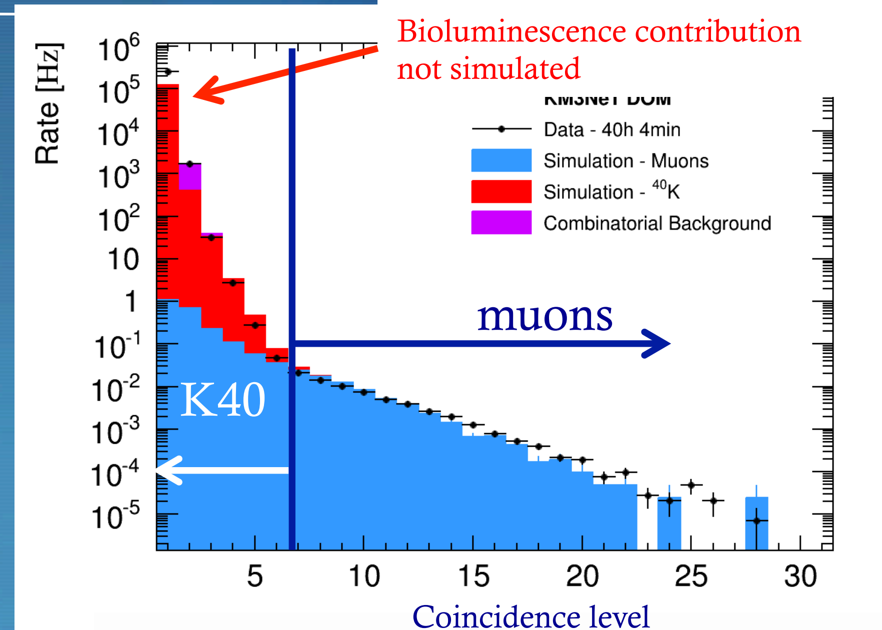


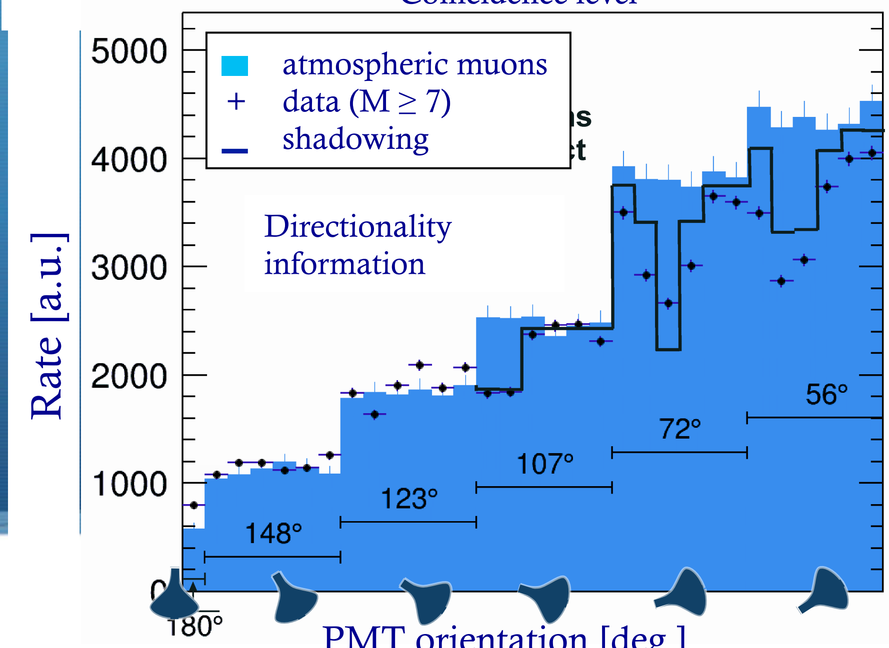


Prototypes – The PPM - DOM

Aprile 2013-November 2014
PPM-DOM at the ANTARES site
(2500 m under s.l.)

Functionality and performance successfully demonstrated





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

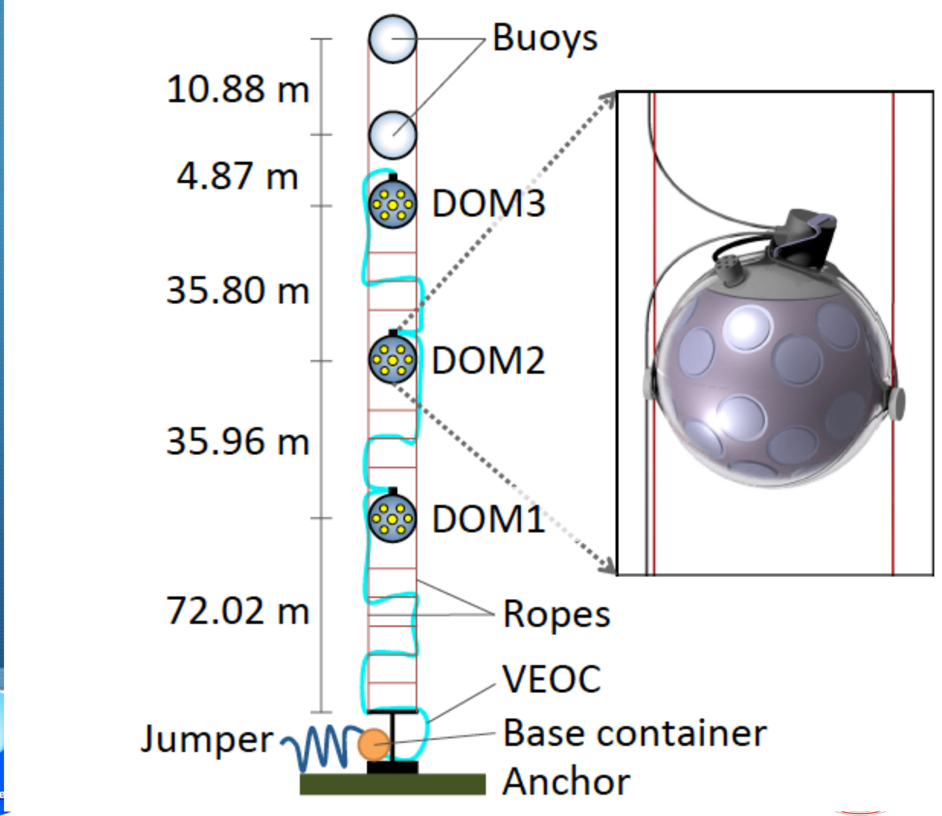
Prototypes – The PPM - DU

DU Prototype with 3 DOMs: proof of DU functionality

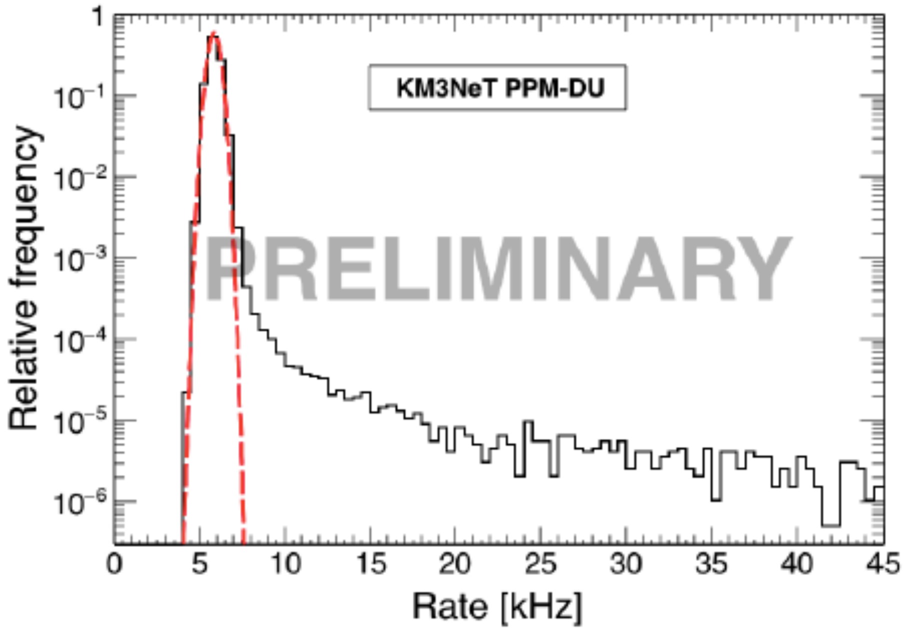
- 2 DOMs with ETEL D783FLA PMTs + 1 DOM with Hamamatsu R12199-02 PMTs
- Test of read-out, DAQ, connection
- Time calibration methodology developed:
  - 40K for intra-DOM calibration
  - LED nano beacons and atmospheric muons for inter-DOMs calibration

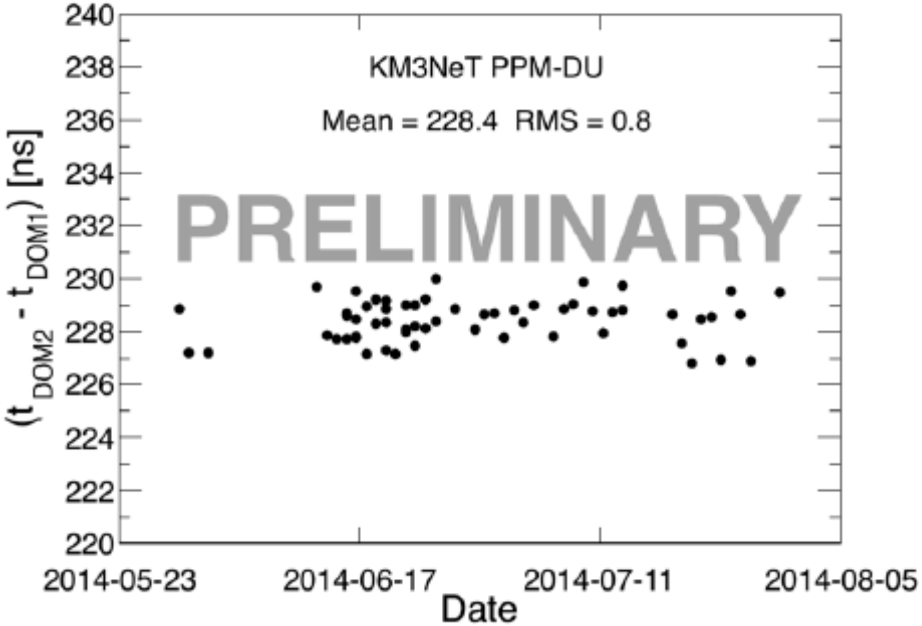
May 2014 / July 2015

17” glass spheres



Some results with PPM-DU



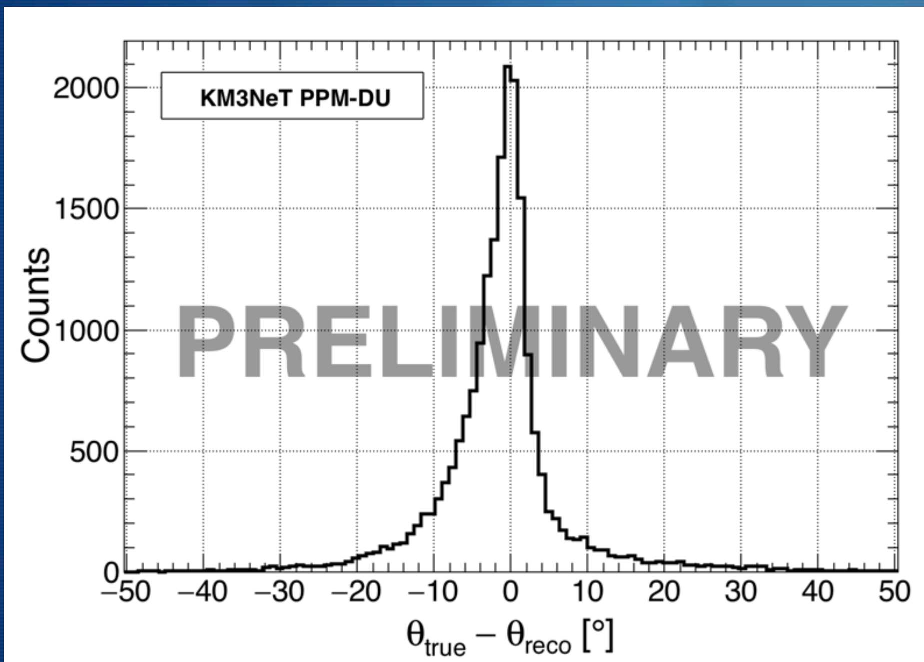


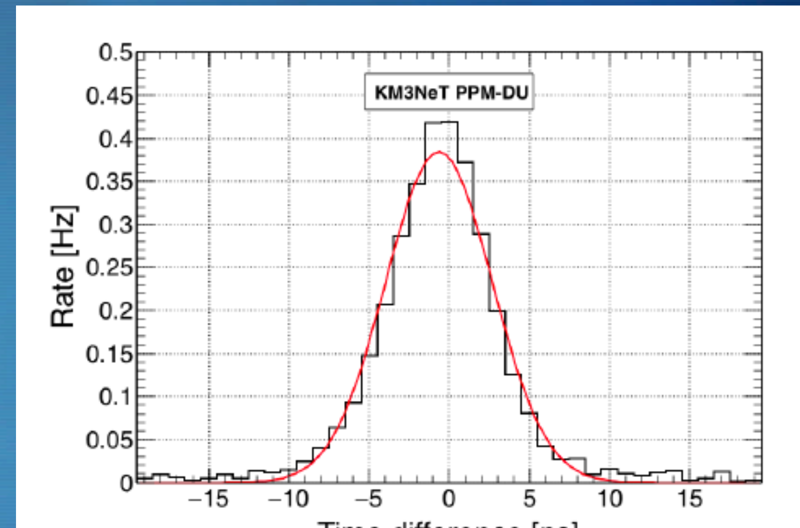
PDF of the mean photon rate
red line = expected Gaussian background due to 40K decay.
The tail is due to bioluminescence

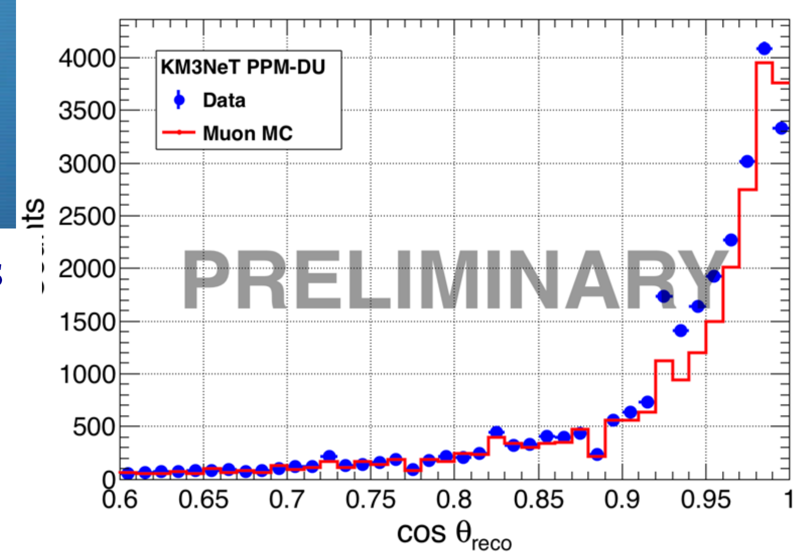
Mean time offsets for DOM 2 wrt DOM1 evaluated with nanobeacon of DOM1.
Time accuracy ~ 1 ns.

PPM-DU Results

intra-DOM calibration
search for coincidences due to 40K decay







Reconstruction of zenith angle of atmospheric muons
Input: positions of the three DOMs and time of the local coincidences
FWHM = 7.6°

KM3NeT timeline

- **KM3NeT Phase-1**

NOW

- completely funded : 31 ME
- construction already started: 2014 – 2016
- 31 detection units to be deployed in 2015-2016
- KM3NeT-It (24 DUs) + KM3NeT-Fr (7 DUs)

- **KM3NeT 2.0 : two site infrastructure**

NEXT FUTURE

- ARCA for HE neutrinos @KM3NeT- It + ORCA for NMH @ KM3NeT-Fr
- Construction : 2017 – 2020
- Additional funding : 90 ME

Proposed to ESFRI
Letter of Intent in preparation

Final detector 3 x 2 Building Blocks in 3 sites
$\approx 3\ km^3$
>2020; additional funding 130-170 ME

KM3NeT Status

- First full DU already integrated and ready for deployment at the KM3NeT-Fr site
- Integration of the second DU in progress. To be deployed at the KM3NeT-It site
- DOM mass production started - 3 integration sites
- DU integration started - 2 integration sites

DOMs ready to be integrated

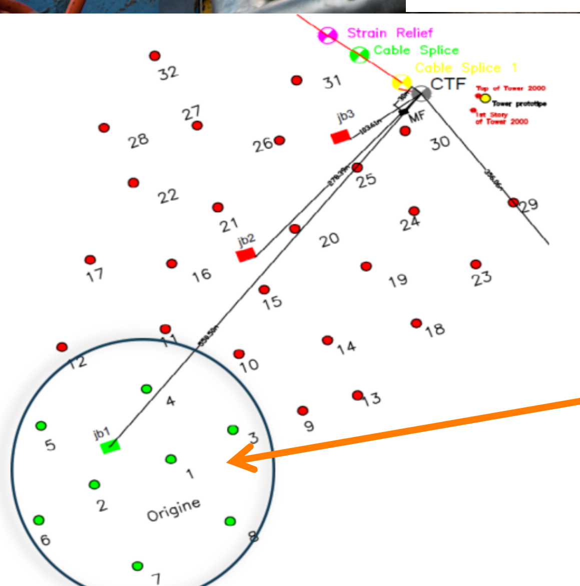
Integration of the base container

Launcher vehicle

KM3NeT – Phase 1 @ Italian site

Cable termination frame
feeds & connects 4 JBs

Shore Station at
Portopalo di Capo Passero



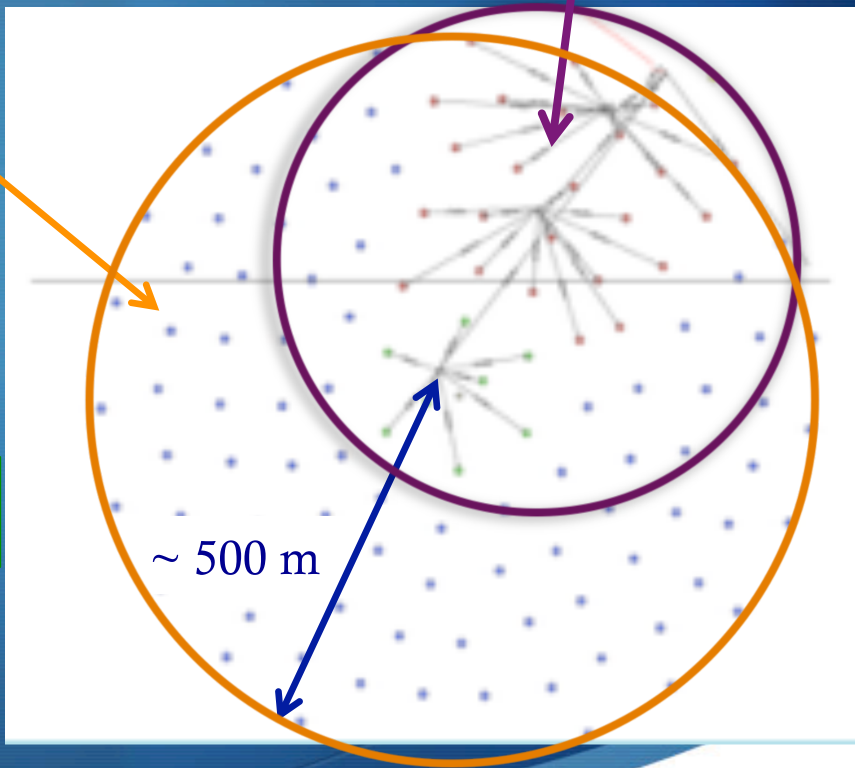
Sea floor network ready for
deployment and connection of DUs

24 string-like DUs + 8 "NEMO" towers

The KM3NeT/ARCA

- ARCA: Astronomy Research with Cosmics in the Abyss
- 1 Building Block = 115 Detection Units
- 2 Building Blocks @KM3NeT-It site
- total volume ≈1 km^3
- 18 DOMs per DU
- Vertical DOM spacing 36 m
- Inter-DU spacing 90 m

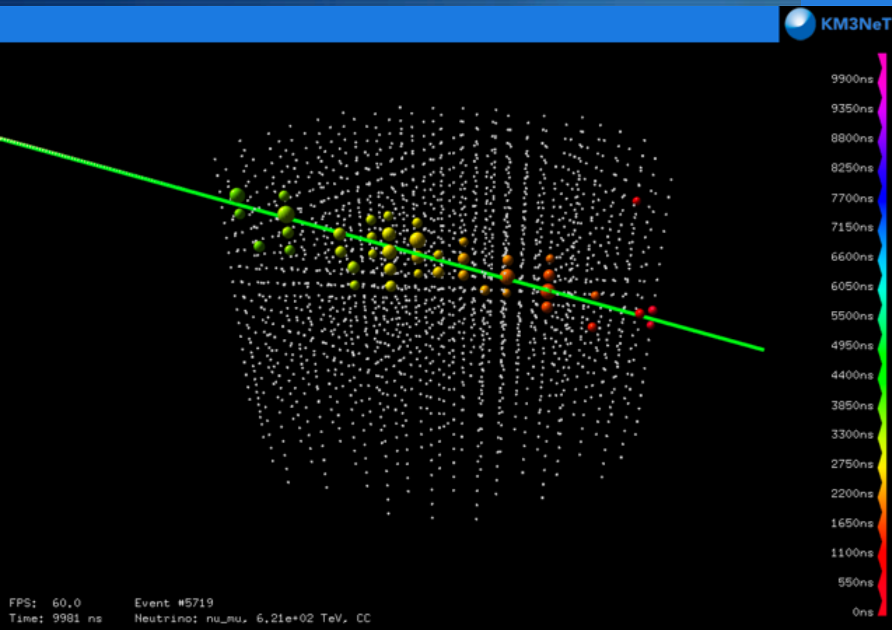
Phase-1

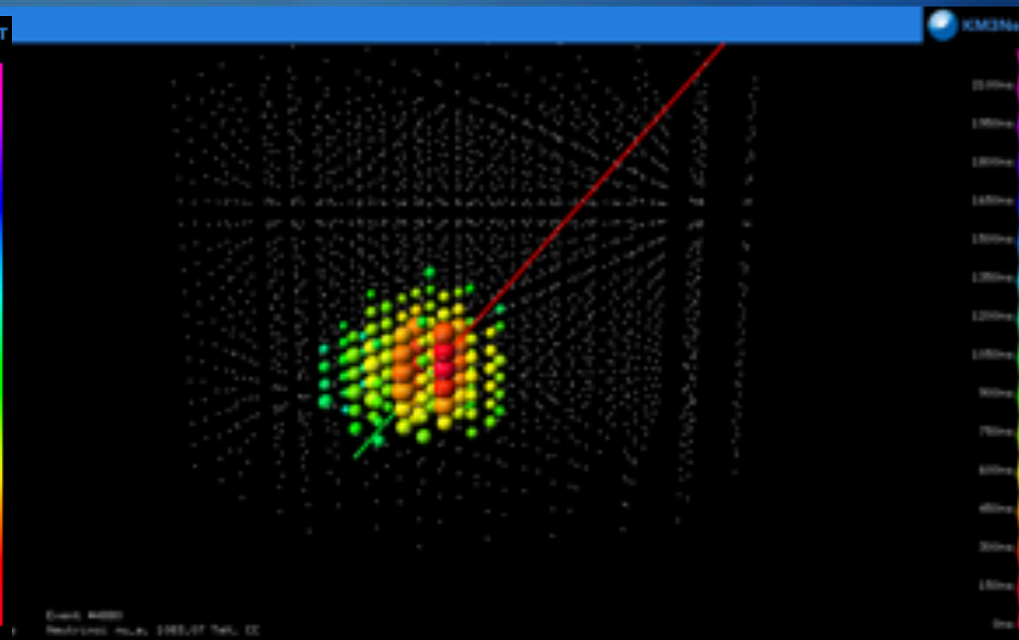


KM3NeT /ARCA =2 x

Performances of KM3NeT/ARCA

“track” and “cascade” events



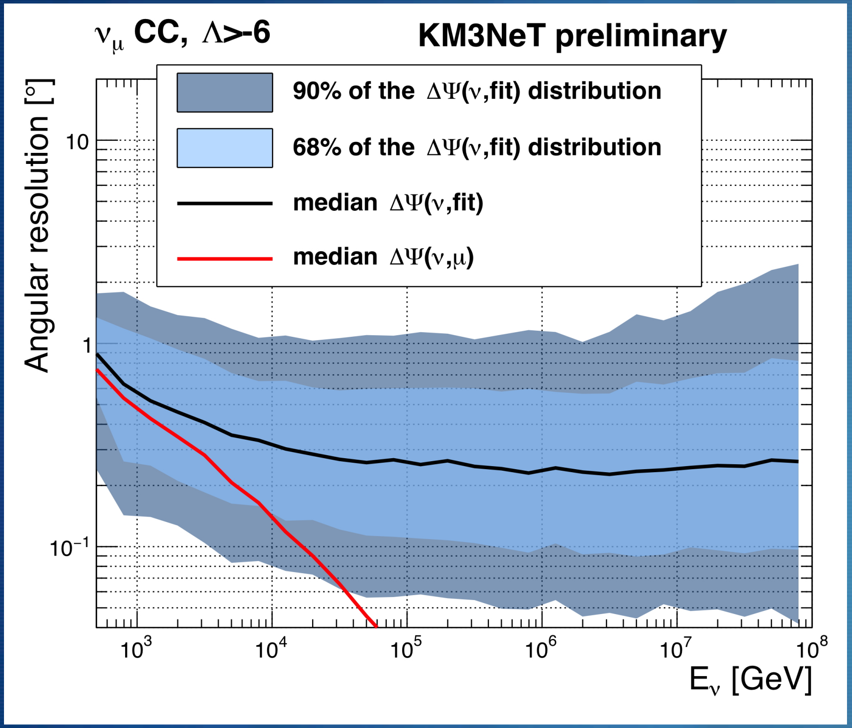


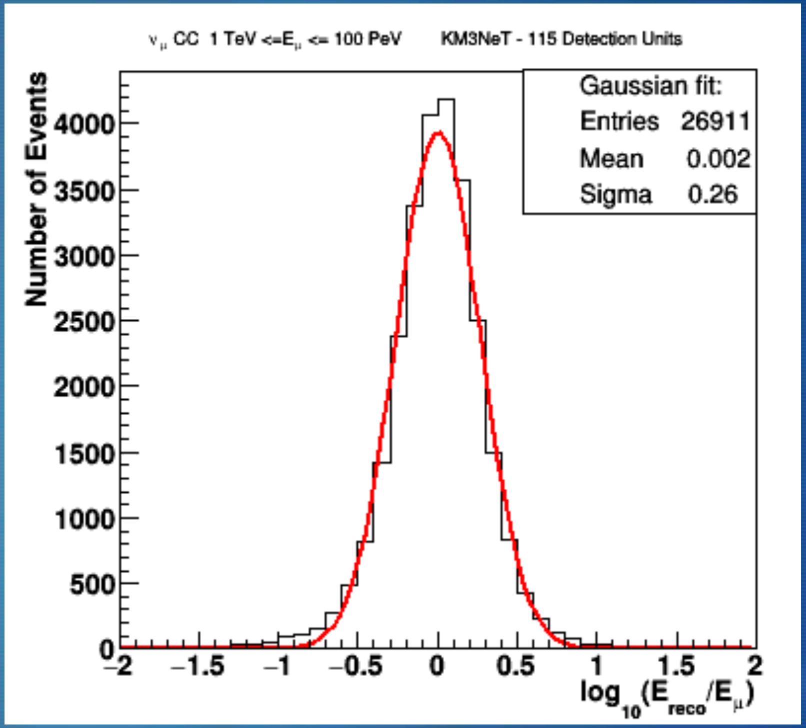
620 TeV CC ν_μ event

1083 TeV CC ν_e event

Reconstruction strategies for both topologies developed

track reconstruction

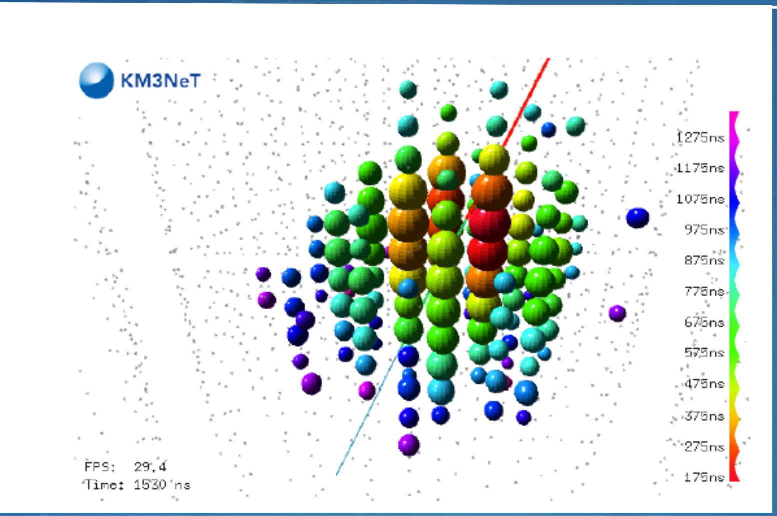




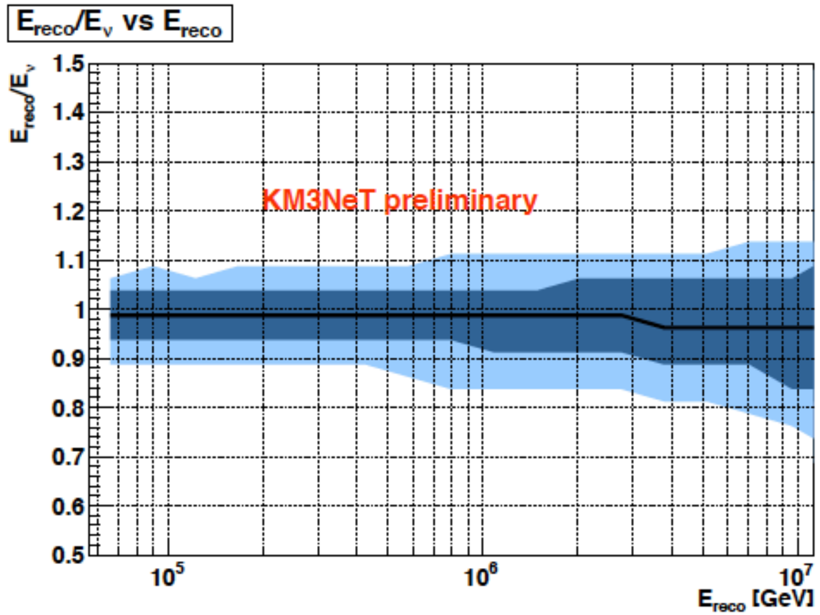
Angular resolution
about 0.2° (E_ν >10 TeV)

Energy resolution 0.26 in $\log E_\mu$
(1 TeV < E_ν < 100 PeV)

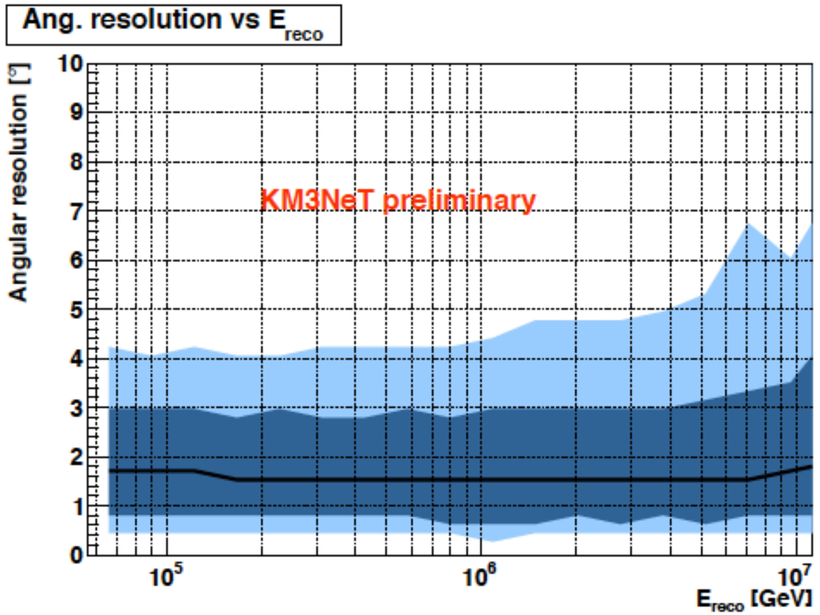
cascade reconstruction



Energy resolution better than 10%



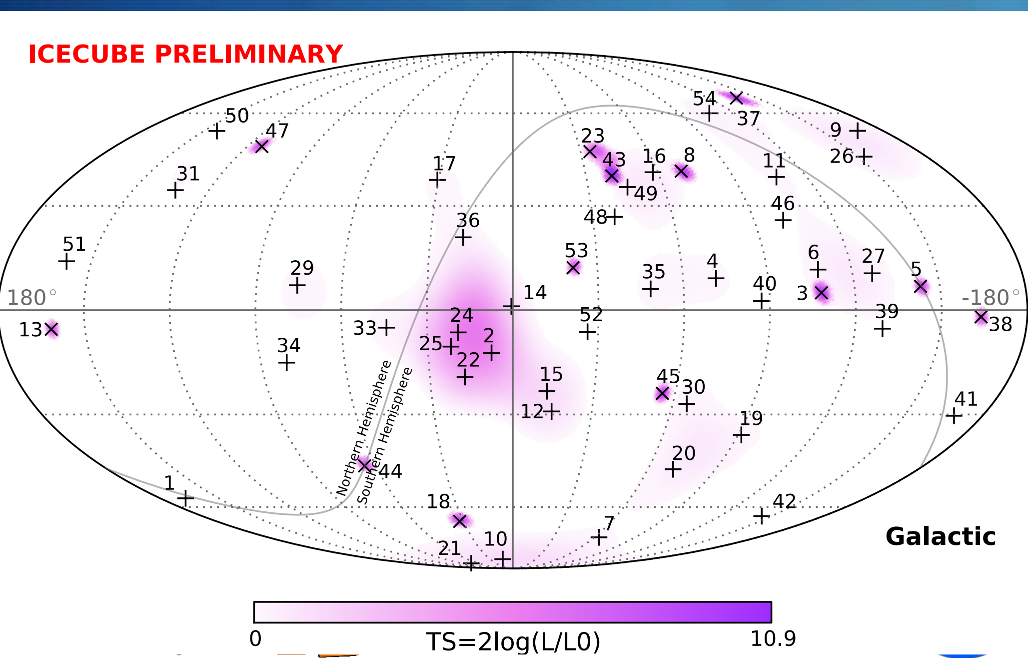
Angular resolution better than 2°

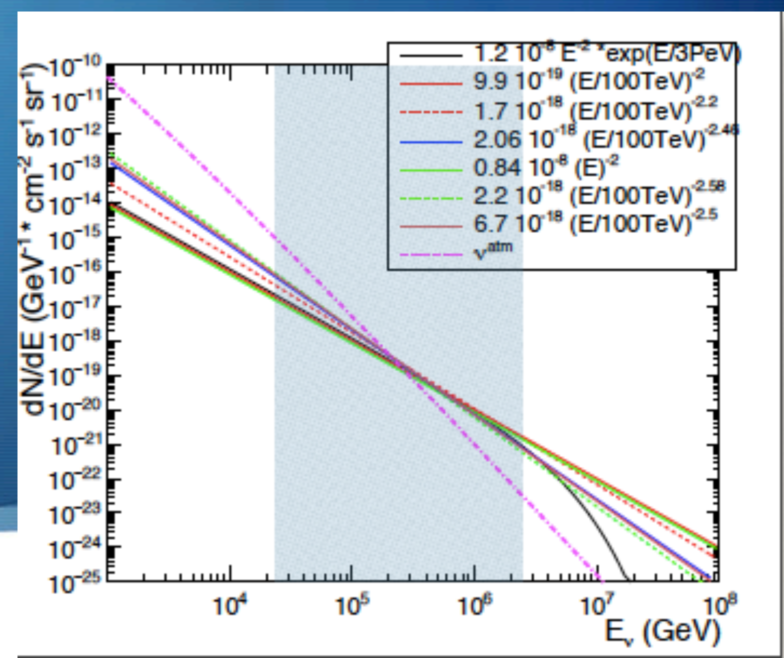


Sensitivity to a diffuse flux

- Measurement of the IceCube flux with a better angular resolution and from a different point of view.
- Benchmark: $\Phi(E) = 1.2\cdot10^{-8}\left(E/1\ \mathrm{GeV}\right)^{-2}\exp\left(-E/3\ \mathrm{PeV}\right)\ \mathrm{GeV}^{-1}\ \mathrm{cm}^{-2}\ \mathrm{s}^{-1}\ \mathrm{sr}^{-1}$
- Due to the uncertainty on the spectral function several fluxes

tested → results are quite similar





Signal and background simulation

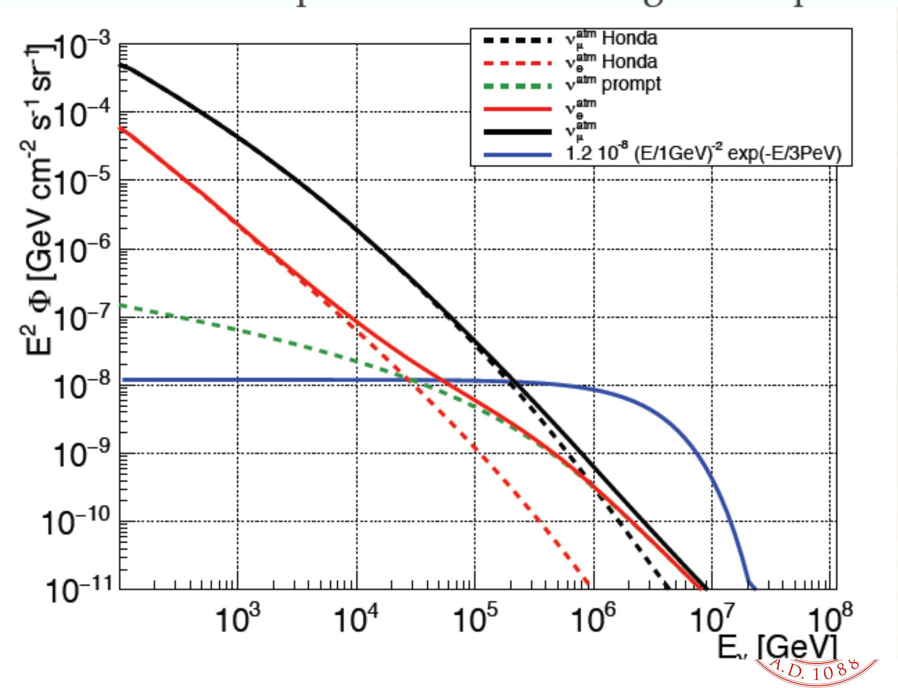
Monte Carlo generation:

- All flavours simulated: cascade and track events.
- Background:
  - large sample of atmospheric muons : about 3 years LT
  - atmospheric neutrinos:

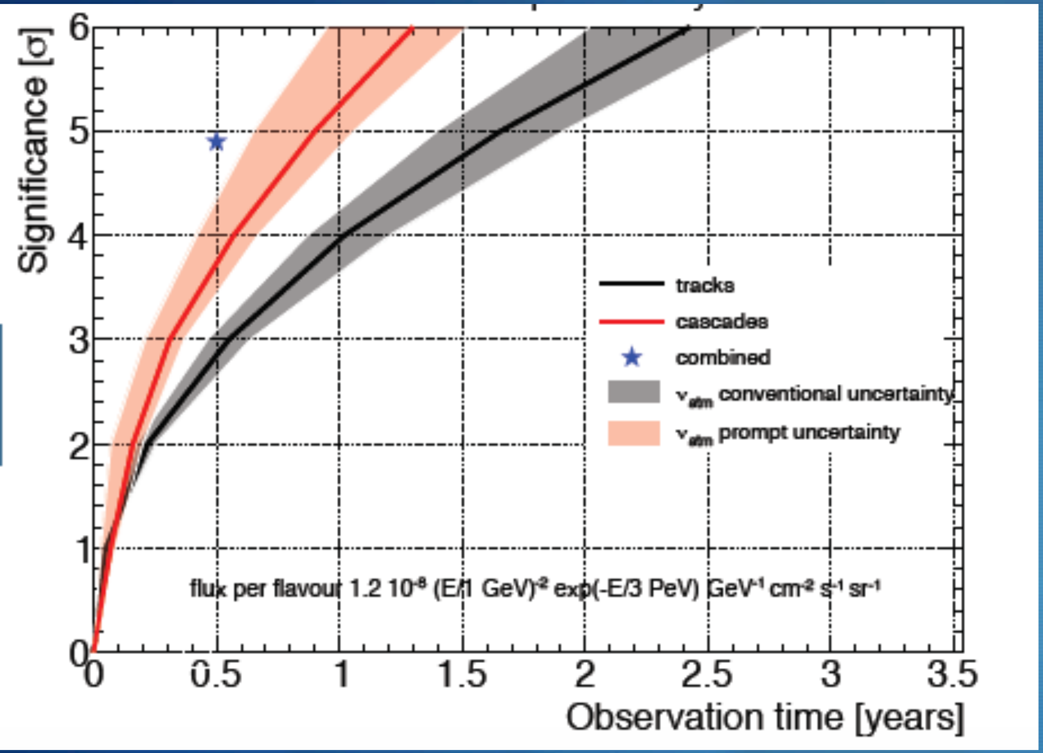
    Honda model for conventional flux

    + Enberg for the prompt component

Source and atmospheric neutrino background spectra



Sensitivity to neutrino diffuse flux



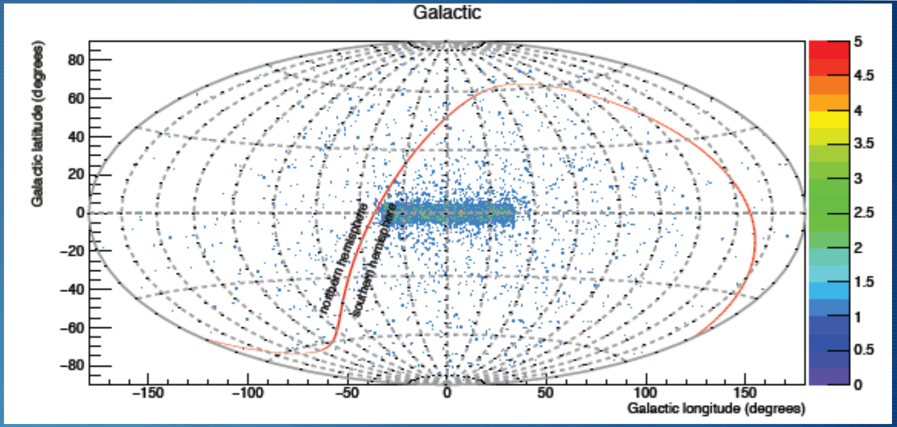
Discovery at 5 σ in less than one year

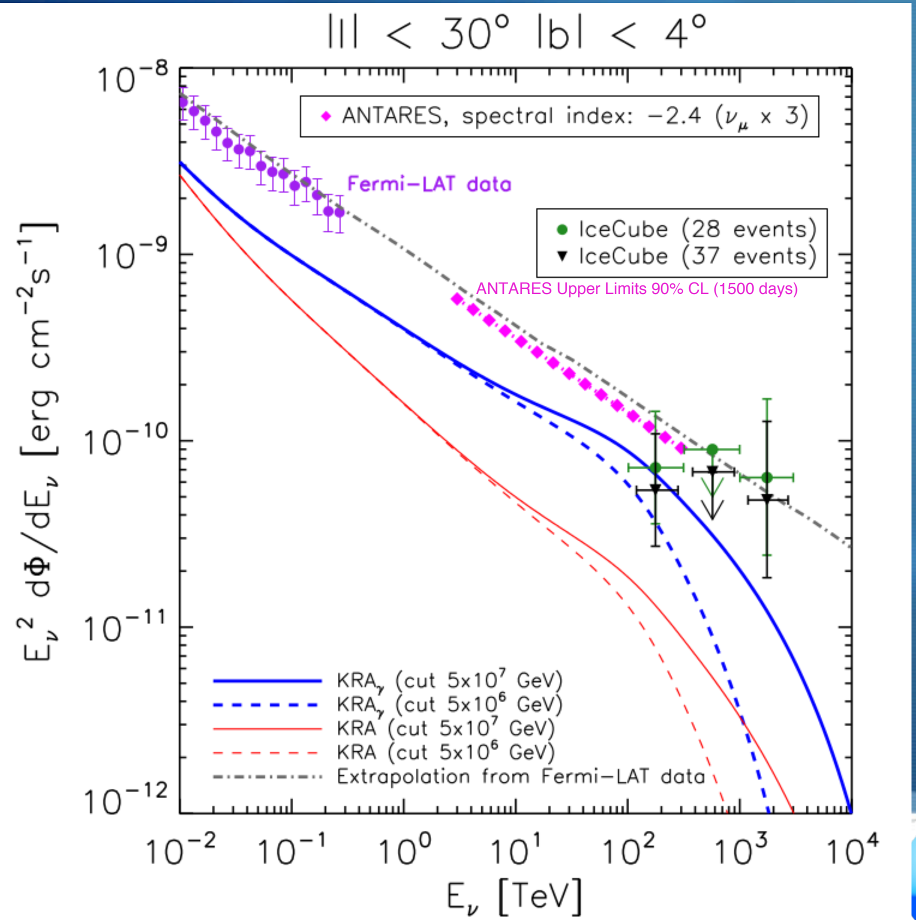
Systematic uncertainty:

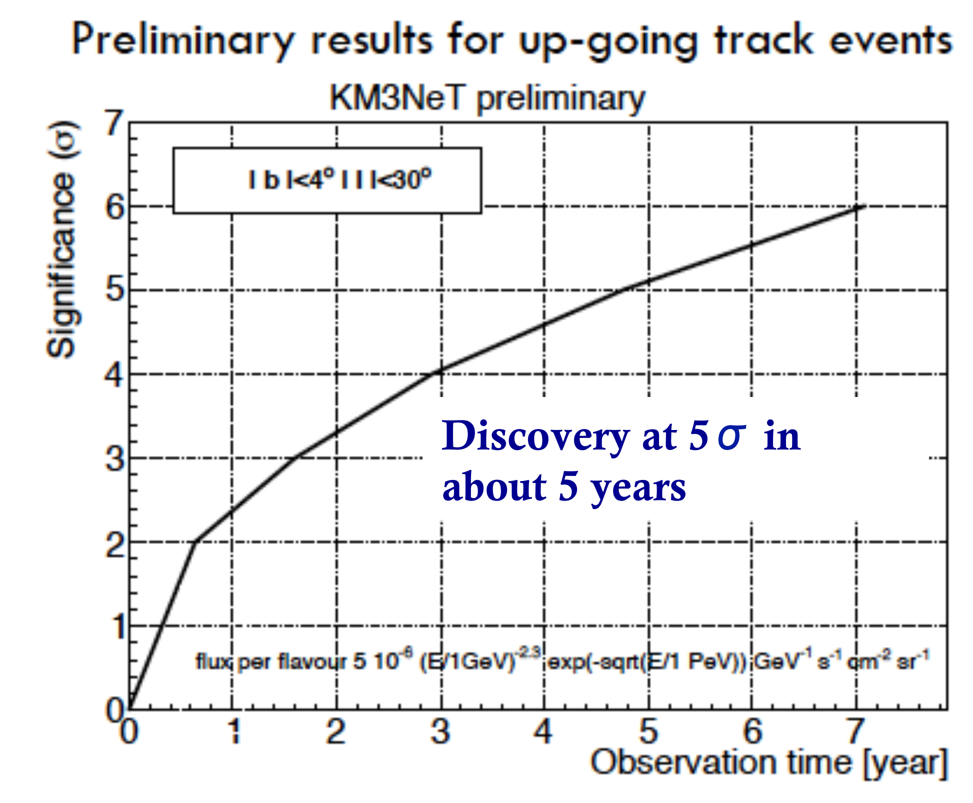
- Scattering length (±10%)
- Absorption length (±10%)
- PMT effective area (±10%)
- Not working PMTs (-10% randomly chosen)
- Random azimuthal rotation of the DOM (3°/6°/9°)
- Atmospheric neutrino flux
  - prompt component (Enberg model high/low prescription)
  - conventional component (Honda flux ±25% in the normalization factor)

Diffuse flux from the galactic plane

Considering an enhanced diffuse flux from the central region of the Galactic Plane

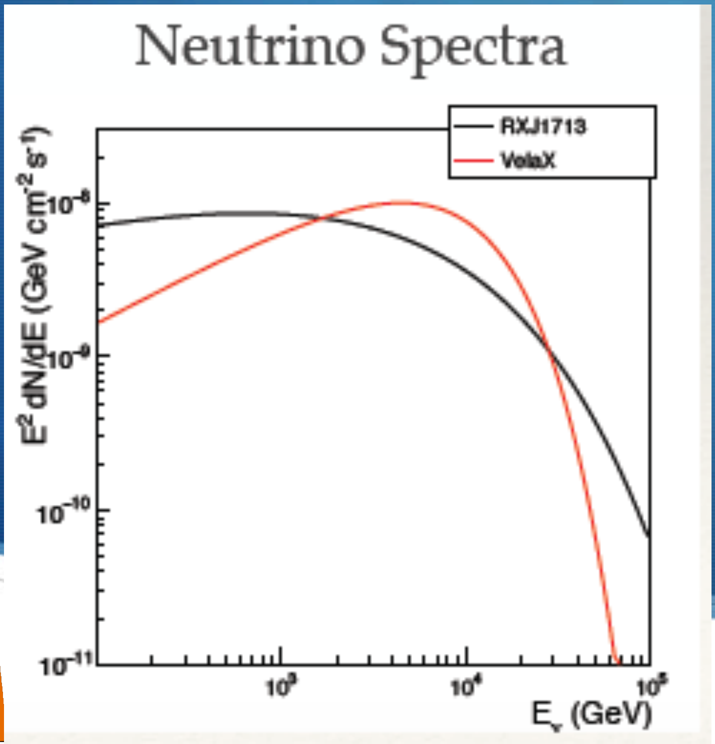




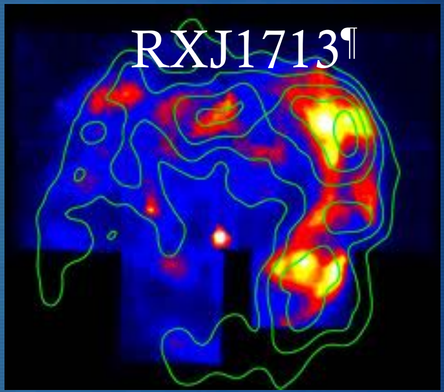


Galactic sources with ARCA -1

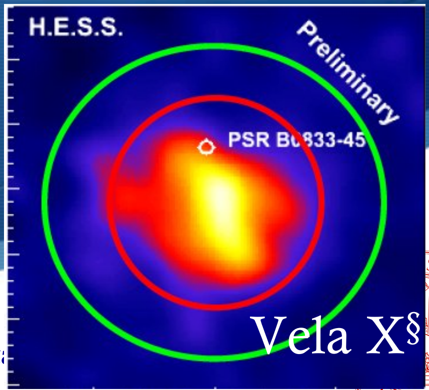
- HE gamma emission observed by HESS in SNRs
- Neutrino spectra predicted using gamma spectra
  - S.R. Kelner, *et al.*, PRD 74 (2006) 034018 (SNR RXJ1713)
  - § F.L. Villante and F. Vissani, PRD 78 (2008) 103007 (PWN Vela)
- 100% hadronic emission and transparent source
- spectra cutoffs of the order of few tens of TeV



Extension: 0.6°



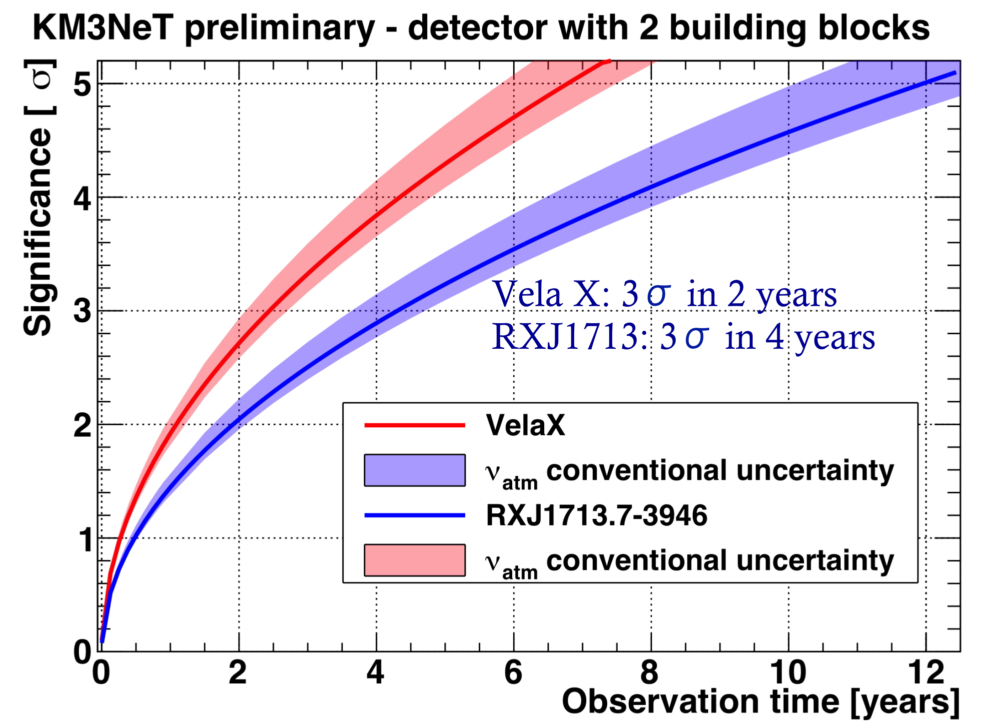
Extension: 0.8°



Istituto Nazionale di Fisica Nucleare
Sezione di Bologna
A. Margiott

Galactic sources with ARCA - 2

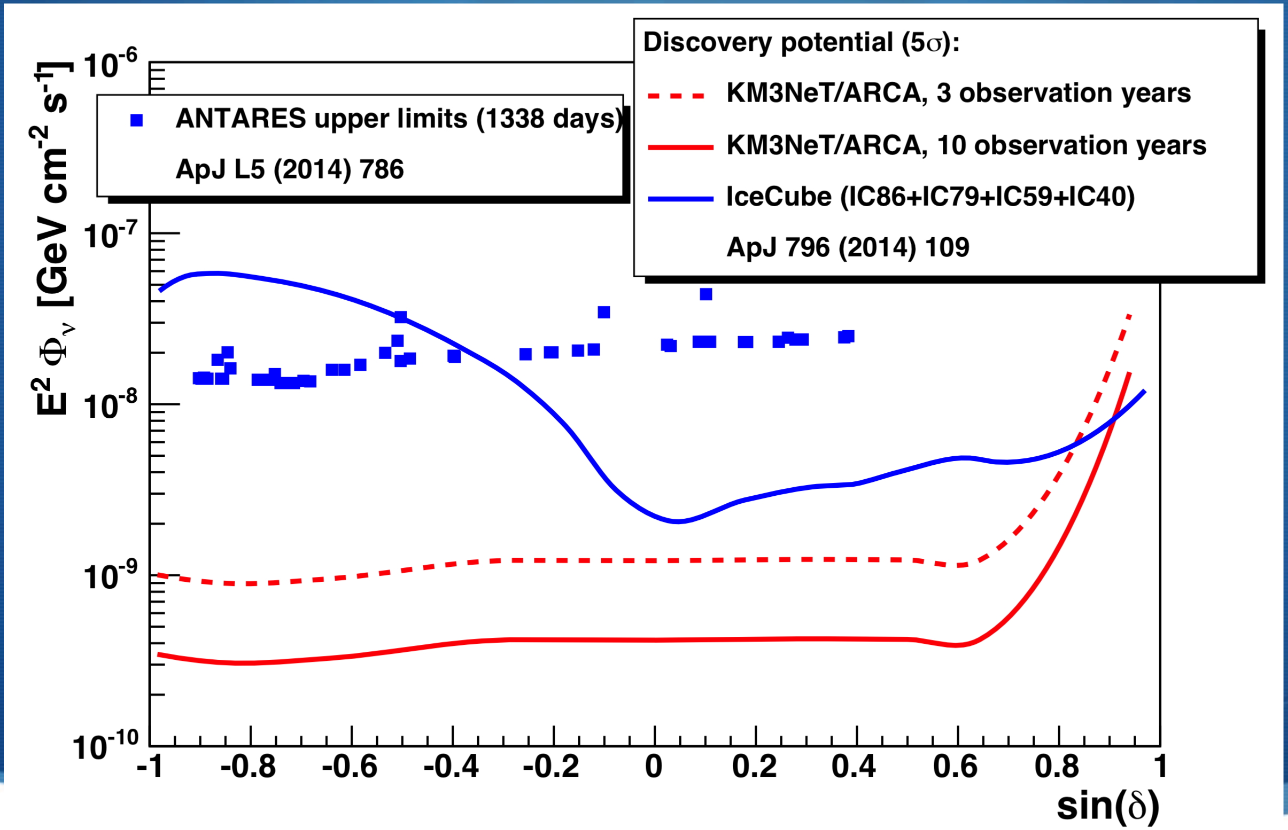
- Analysis with upgoing muon neutrino – golden channel
- Preselection cuts applied to reject most of the atmospheric neutrino background
  - cuts on reconstructed zenith angle and source radius
- Final cut based on the Multivariate analysis (Boost Decision Tree)
- Evaluation of the flux at different significance with unbinned method -> Max. likelihood method



- Angular resolution < 0.2° for E_ν > 10 TeV
- Energy resolution 27% in $\log(E_\mu)$ for 10 TeV < E_μ < 100 PeV

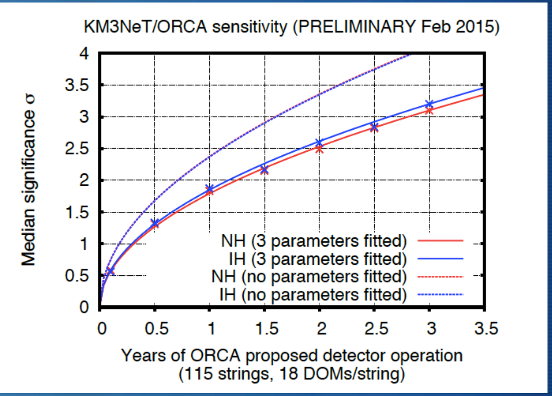
E^{-2} spectra

Very large field of view – discovery potential for point-like sources with a spectrum proportional to E^{-2}



Not only HE neutrinos : ORCA

- Measuring matter-induced modifications of neutrino flavor oscillation probabilities by detecting atmospheric muon and electron neutrinos traversing the Earth interior.
- High precision measurement: few percent differences in the event count. Good discrimination event topology.
- Systematic uncertainties :
  - efficiencies of the photosensors + absorption length of light in water
  - neutrino flux & hadronization models
  - oscillation parameters



- Likelihood ratio calculated by testing both hypotheses (NH/IH) on the events
- Same technology as in ARCA, but denser configuration of detection units, @KM3NeT-Fr site
  - Inter-string distance 20 m; vertical DOM spacing 6-18 m (to be optimised)
- E-O cable and Junction Box already deployed and connected →6 strings by 2016 (Phase-1)
- In 3 years full ORCA (1 Building Block – 115 DU) ready, if more funds available (+ 40 ME)

Summary

- The KM3NeT collaboration is building a network of neutrino telescopes in the Mediterranean Sea
- Investigation of the neutrino sky with unprecedented resolution
- Complete coverage of the neutrino energy range:
  - ARCA for high energy cosmic neutrinos →unprecedented resolution
  - ORCA neutrino mass hierarchy and oscillations with 1GeV< E_ν<100 GeV
- KM3NeT/ARCA (≈ 1 km3) @ the Italian site
- KM3NeT/ORCA @ the French site
- Phase-1 started and completely funded
- Following phase : KM3NeT 2.0