Neutrino Astronomy in the Mediterranean: Past, Present and Future

R. Bruijn

Universiteit van Amsterdam/Nikhef

IPA 2015 Symposium, Madison

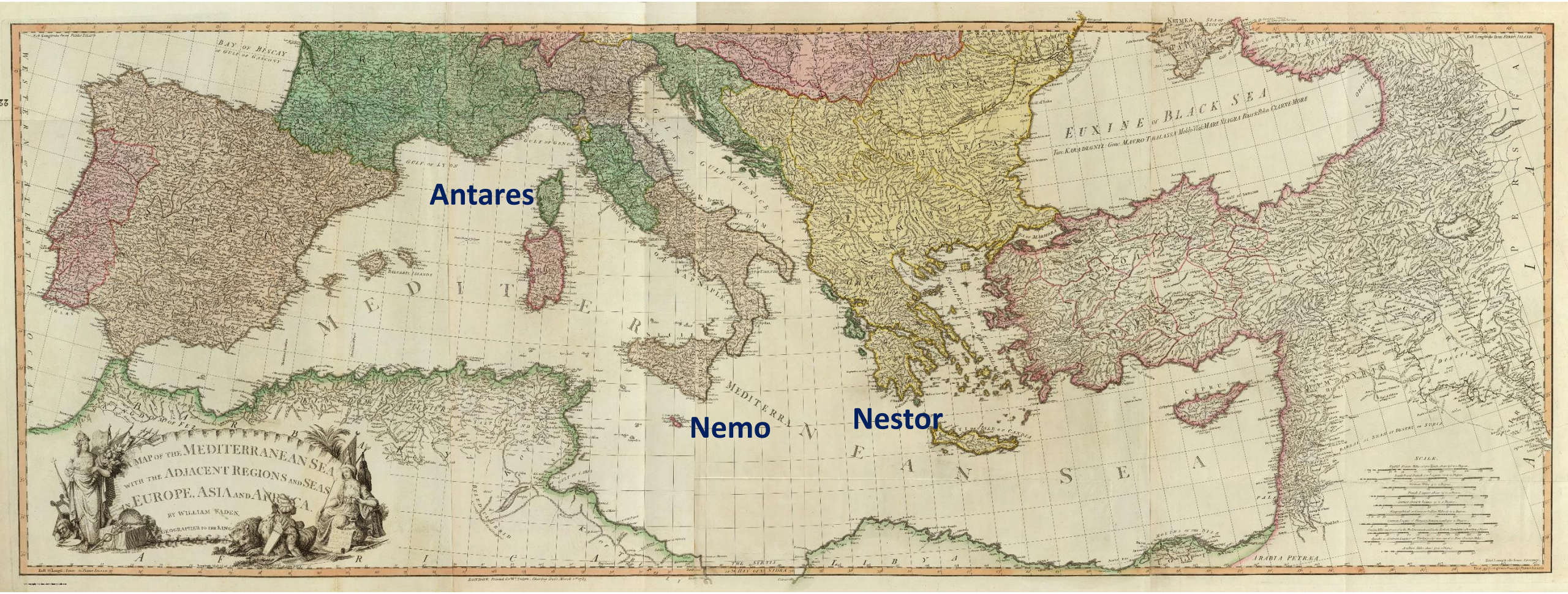
Nikhef

KM3NeT

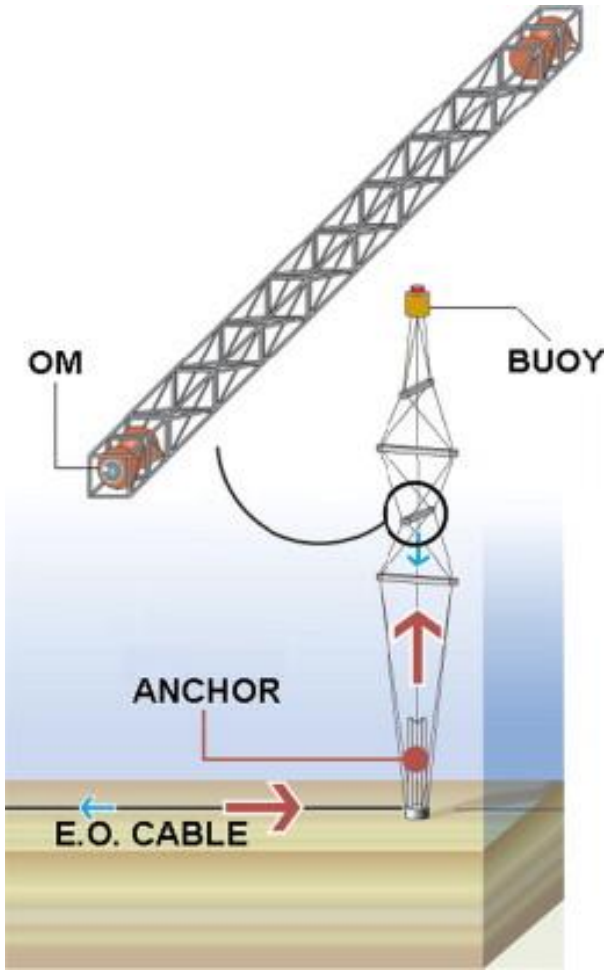
ANTARES

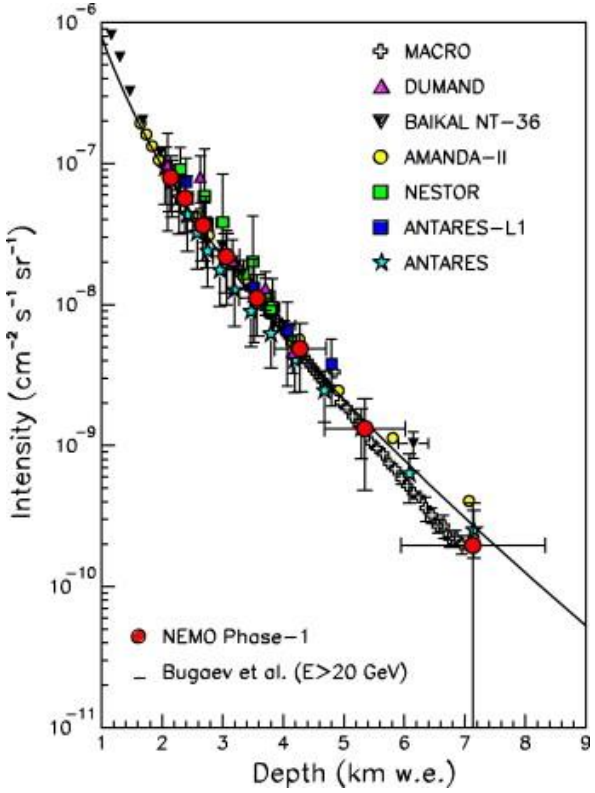
UNIVERSITEIT VAN AMSTERDAM

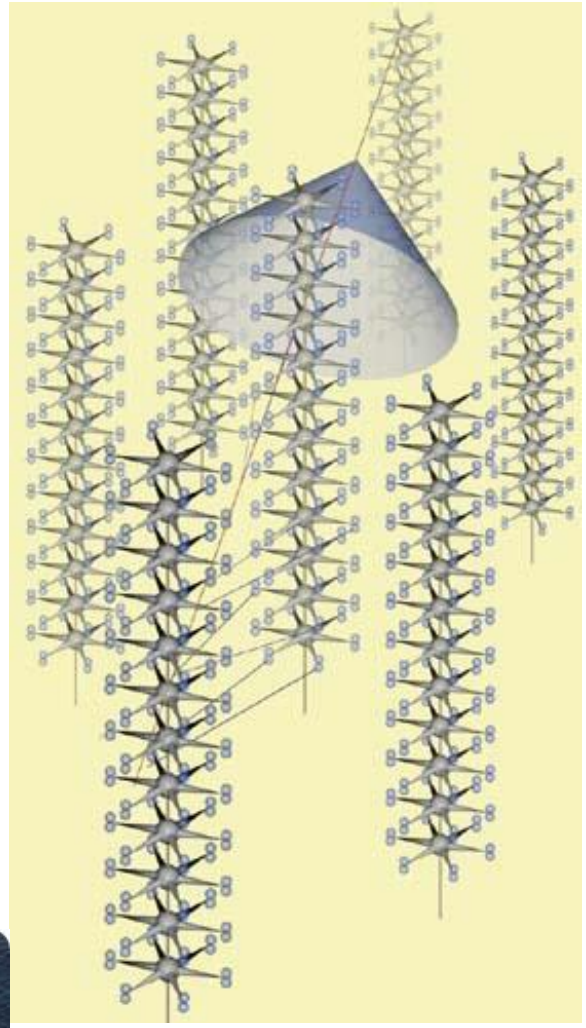
The past (1992-now)

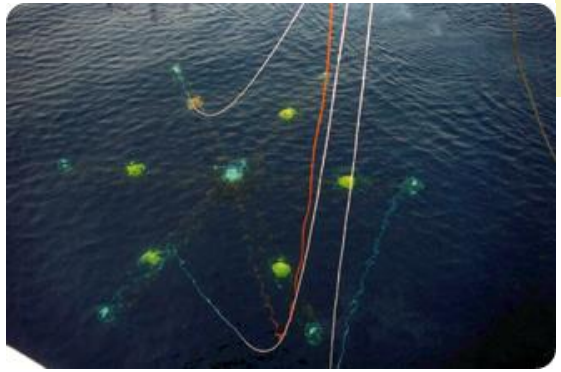


Nemo and Nestor





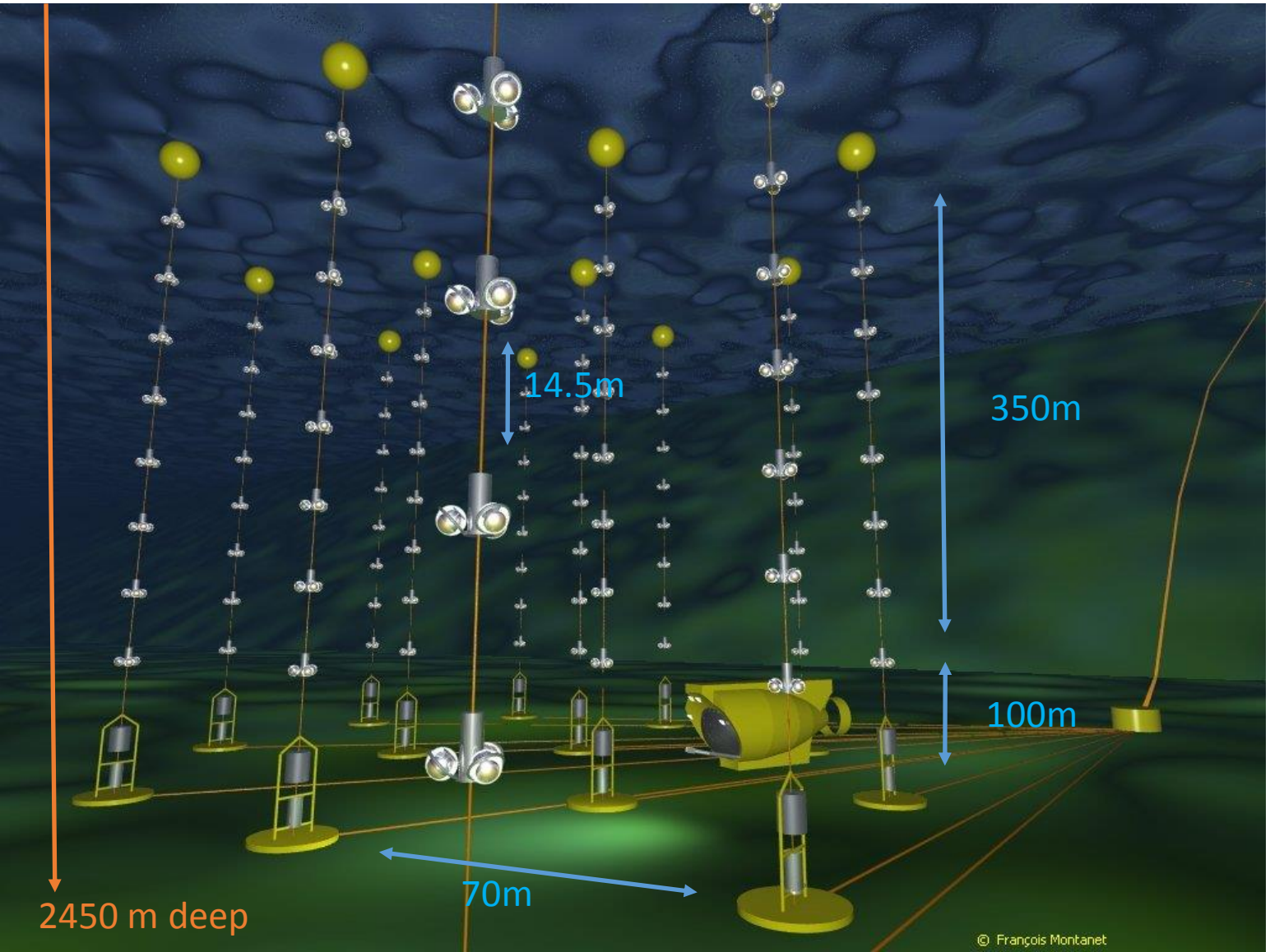




Nemo Collaboration
Astropart. Phys., 33
(2010), p. 263

Nestor Collaboration
Astropart.Phys. 23
(2005) 377-392

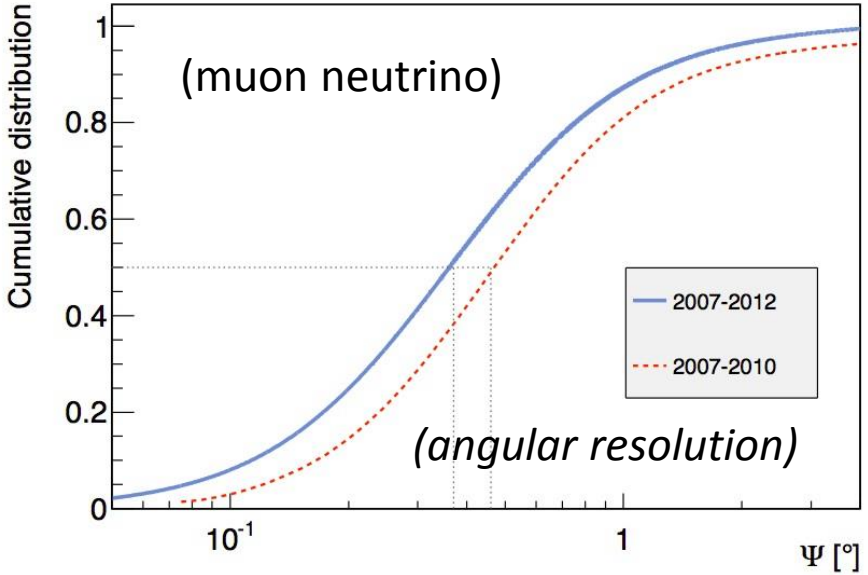
Antares (past & present!)



- Operational since 2007
- 8 countries, 31 institutes, 150 scientists
- Program:
  - Neutrino astronomy
  - Multi-messenger
  - Dark Matter
  - Atmospheric neutrinos
  - ´Exotics´: nuclearites, monopoles
  - Acoustic detection
  - Sea Science

Some selected results will follow

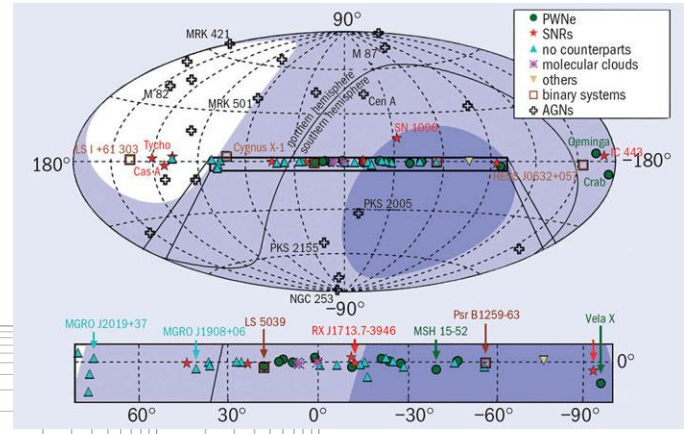
Antares/The Mediterranean Sea

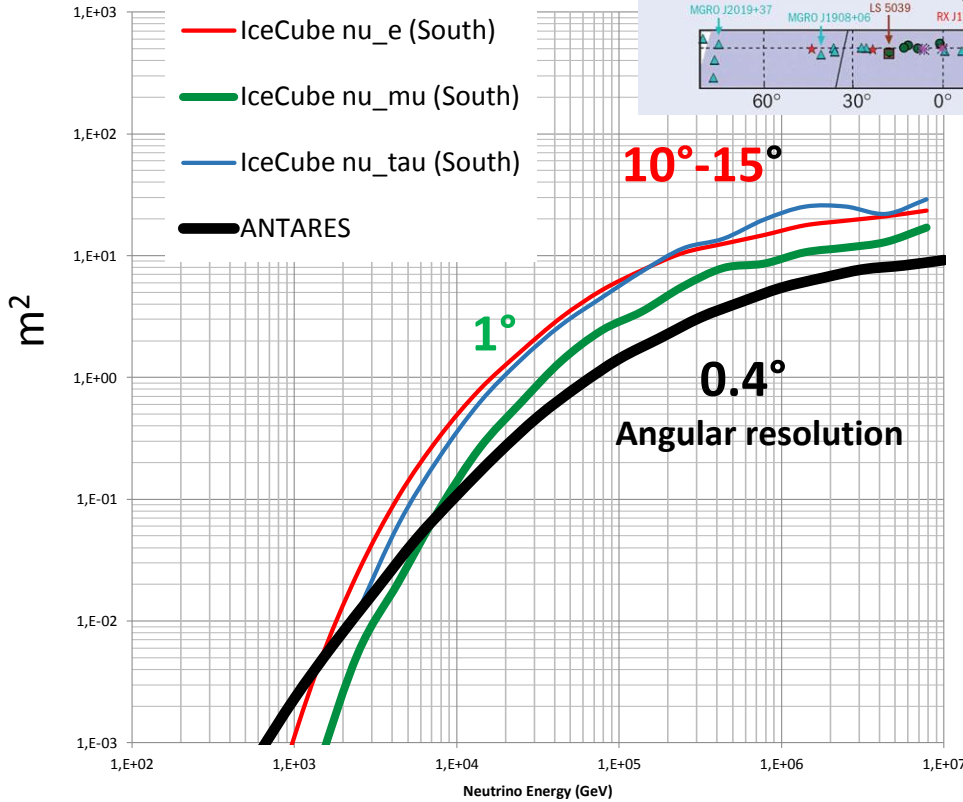


Low scattering allows for good angular resolution

(Shower resolution similar to that of KM3NeT)

Note: for point source searches the background scales with *resolution*^{2}





(Effective area)

Neutrino energy [GeV]

ANTARES ApJ 760:53 (2012)
IceCube PRD91 (2015) 2, 022001

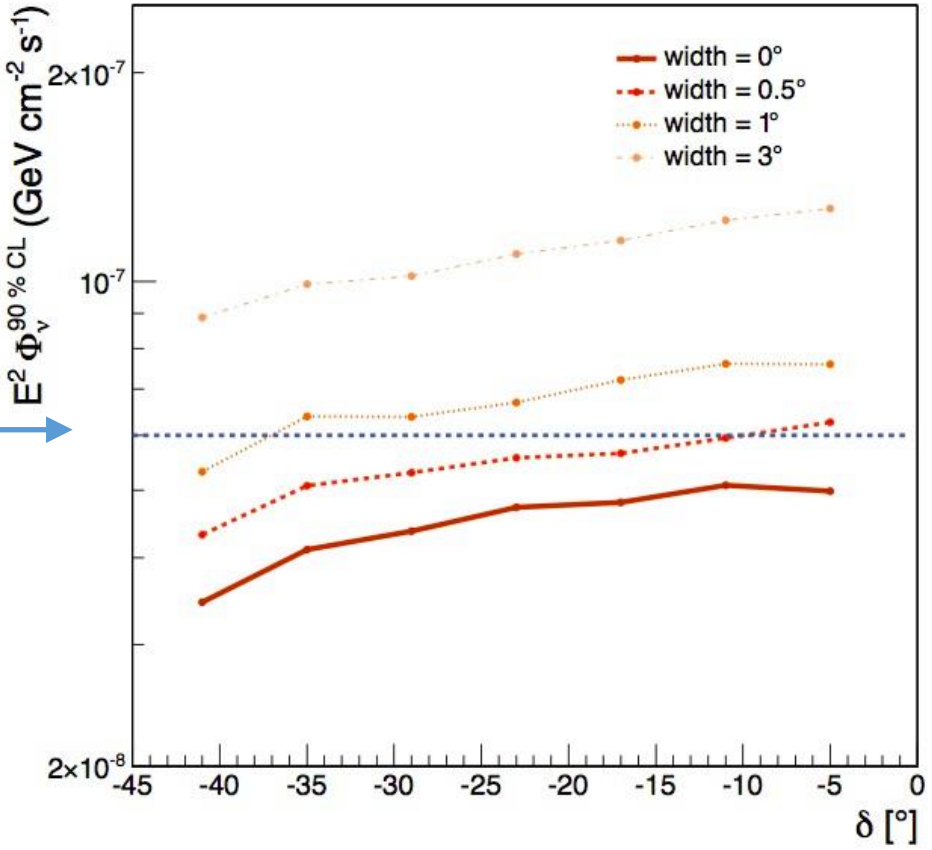
Location of the detector(s) allow for a view of the Galactic Plane
("Down" in IceCube is "up" in Antares/The Mediterranean)

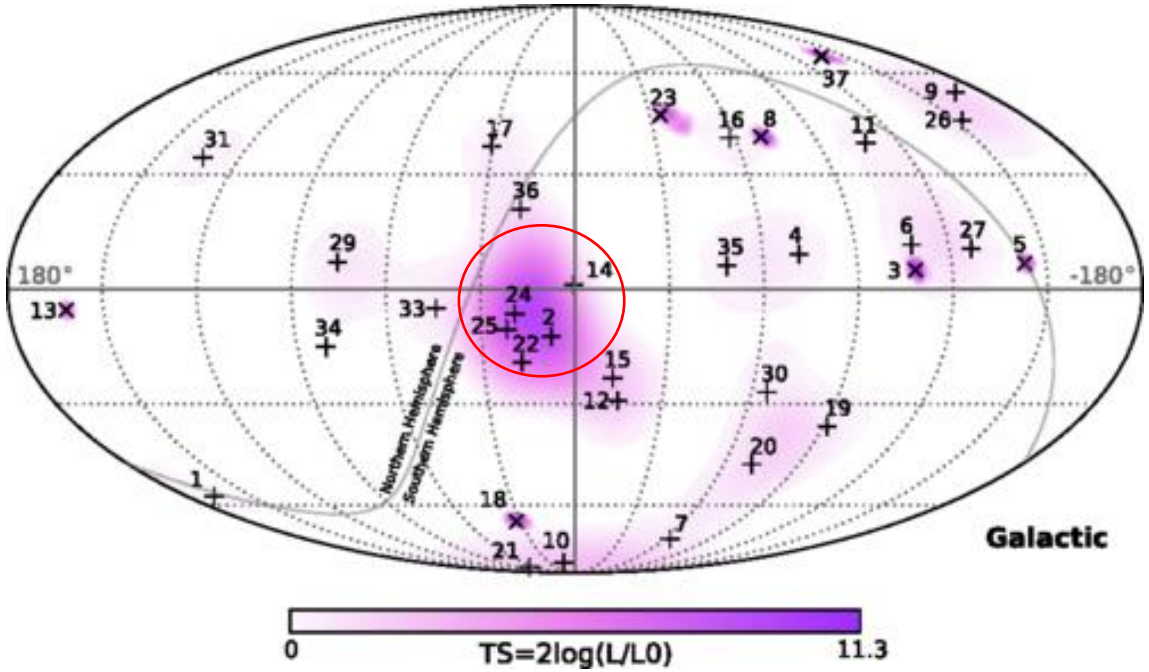
Antares – Galactic Source?

Possible Galactic source motivated by accumulation of IceCube events
Hypothesized flux for a source at (α,δ)=(−79°, −23°):

$\Phi = 6 \times 10^{-8} E^{-2}$ GeV cm^{-2} s^{-1}

(*Gonzalez-Garcia et al, APP 57 (2014)*)



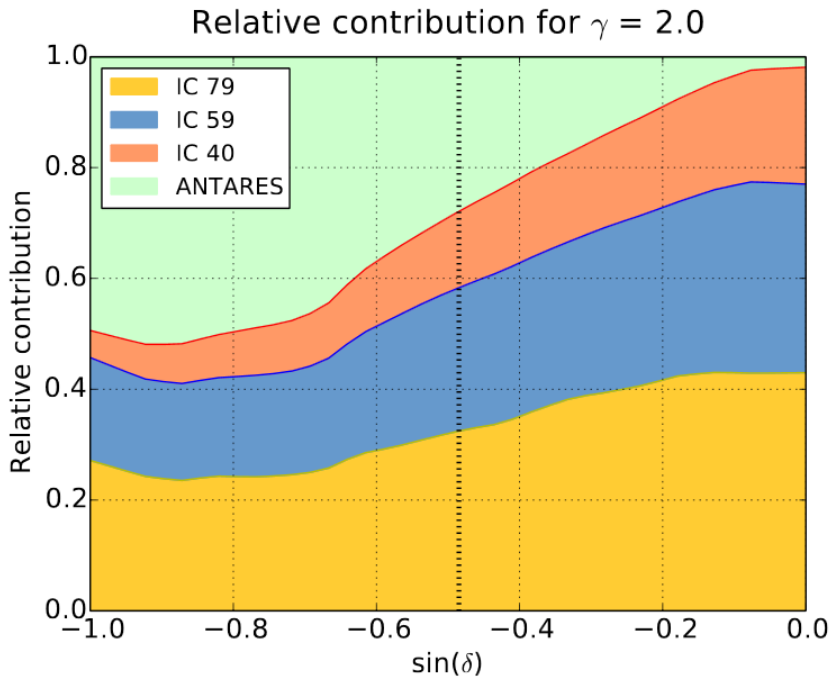


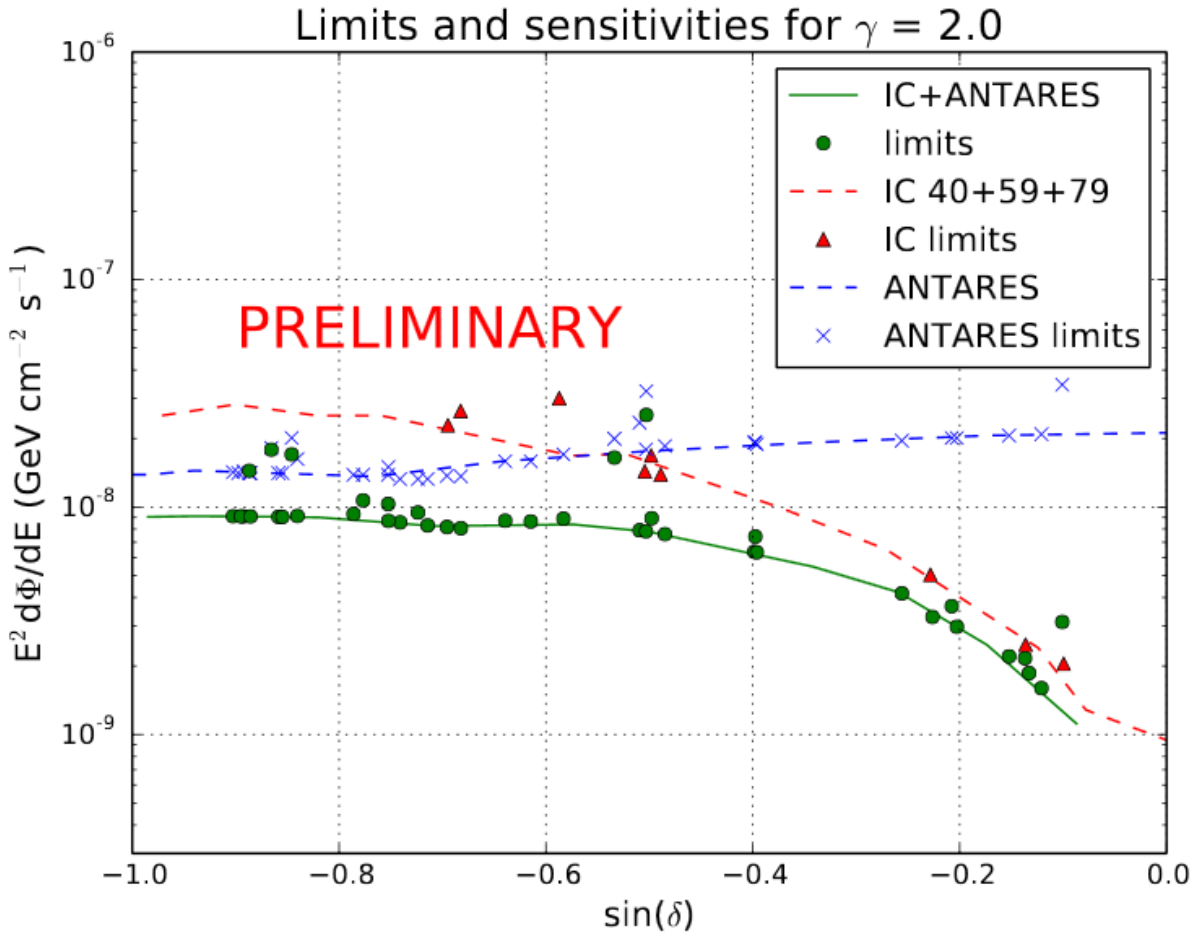
Antares excludes single point source as origin of hotspot around Galactic Center in a region of 20°
(Astrophys. J. Lett. 786:L5 (2014))

Antares – Combined IceCube/Antares search

Combined Southern Hemisphere search with 2007-2012 Antares and IC40, IC59, and IC79 samples

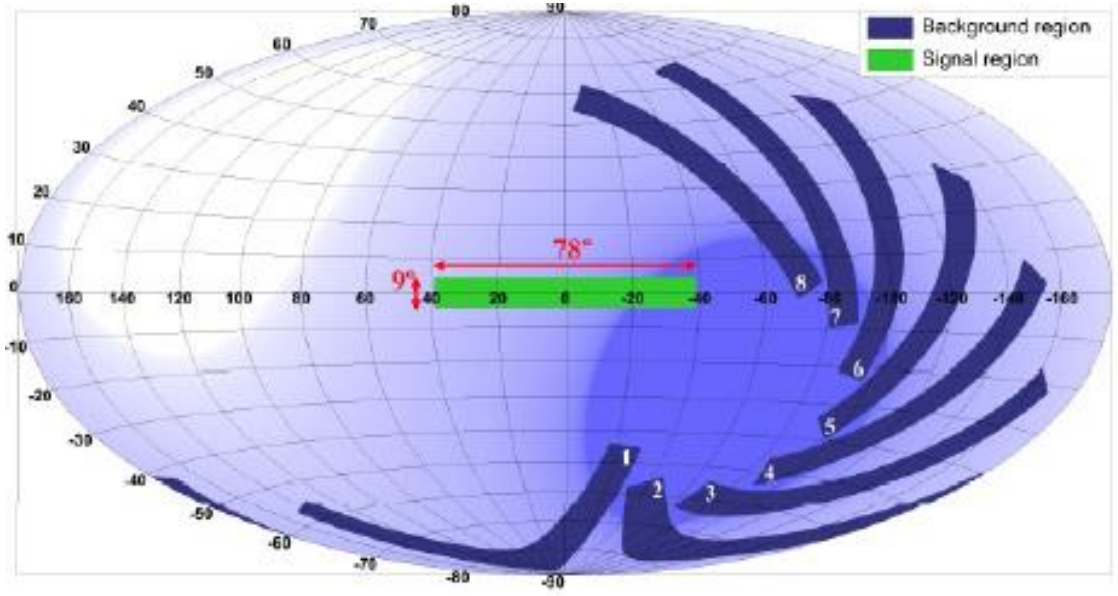
Hypothesized fluxes: $\frac{d\Phi}{dE} = \Phi_0 E^{-2} e^{-\sqrt{\frac{E}{E_{cutoff}}}}$





(Note: Antares probes Southern sky at lower energies than IceCube, this is relevant for Galactic sources)

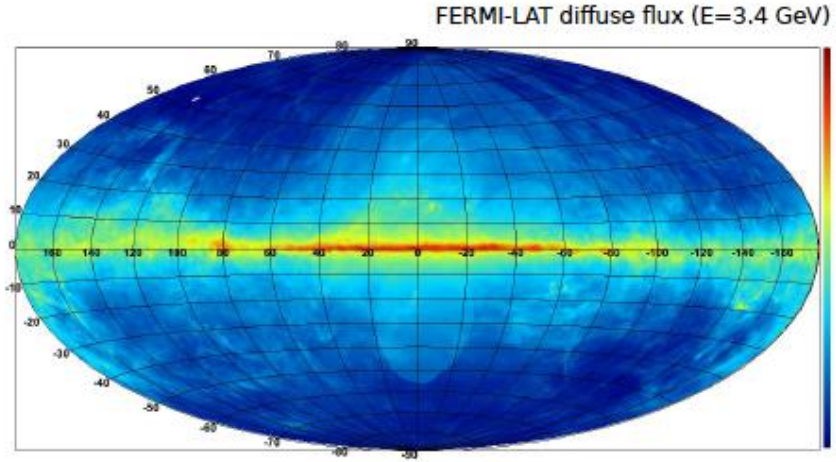
Antares – Galactic Ridge

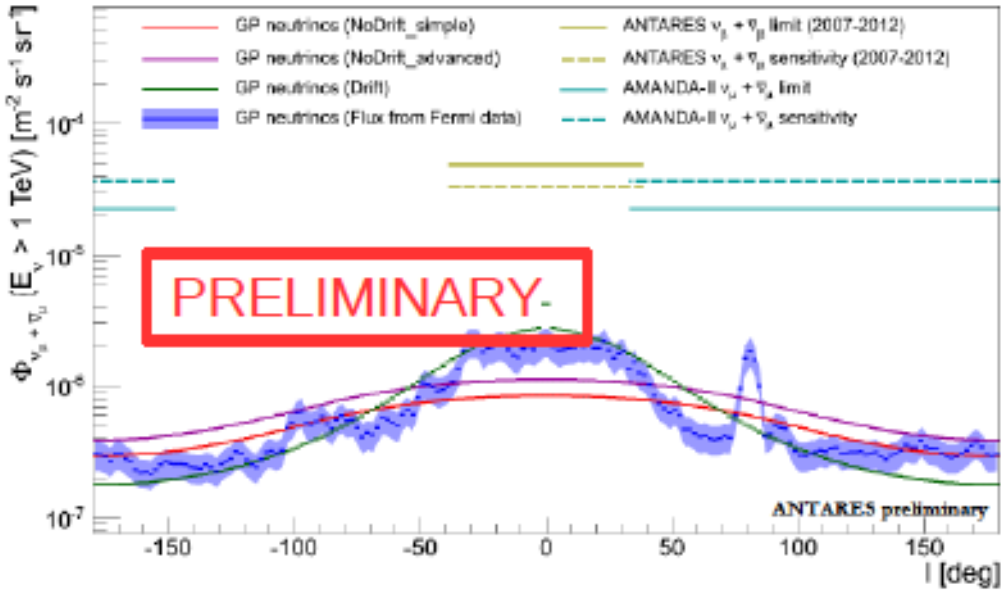


On/Off Zones (N_{off}=8)
Optimized for different models and MRF

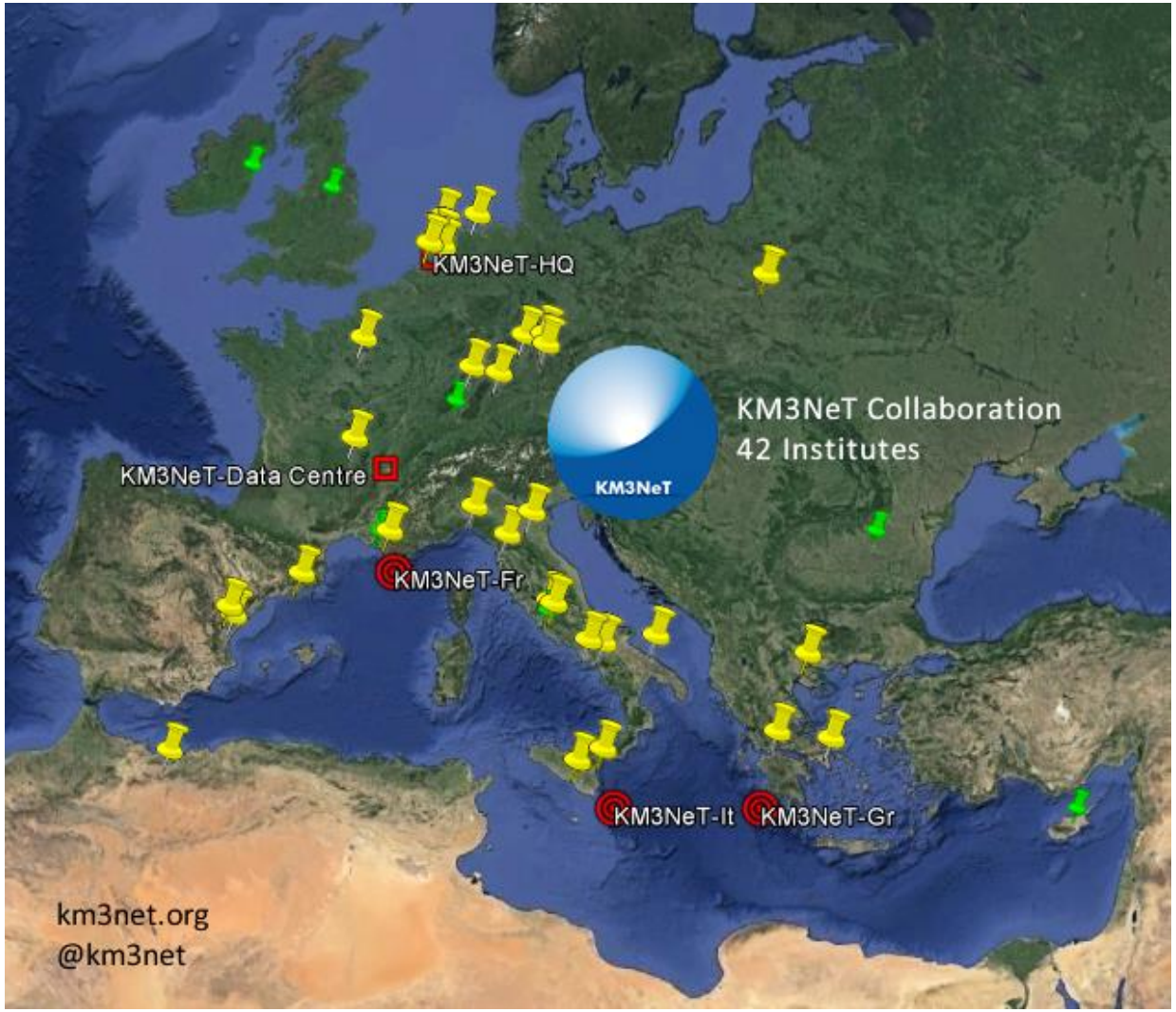
Data from 2007-2011:
N_{obs}: 177, N_{exp}: 166

0.8 σ excess, 90 % limits set





Present* and Future: KM3NeT



*: design phase started in 2006

KM3NeT builds on a long and succesful experience of exploiting the Mediterranean waters as a neutrino telescope

KM3NeT: phased approach

Phase	Building blocks	Primary Deliverables	Remarks
1	0.2	Proof of feasibility and first science	
2	2	High resolution studies of neutrino signal reported by IceCube. All flavour neutrino astronomy	“ARCA”*
	1	Neutrino mass hierarchy	“ORCA”*
3	6	Neutrino astronomy	

Present

Future

(Science driven)

*: Astroparticle & Oscillations Research with Cosmics in the Abyss

PMTs+DOM

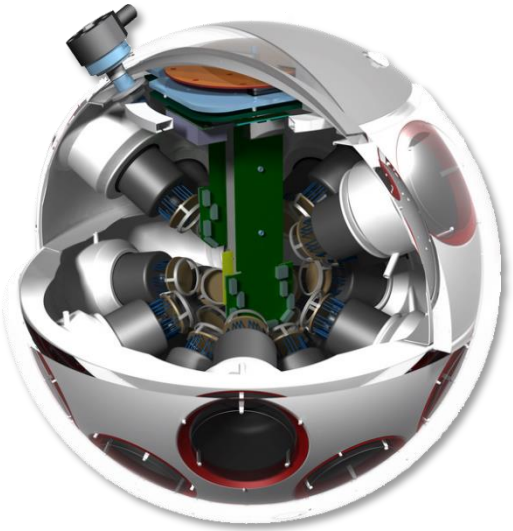
PMT Features:

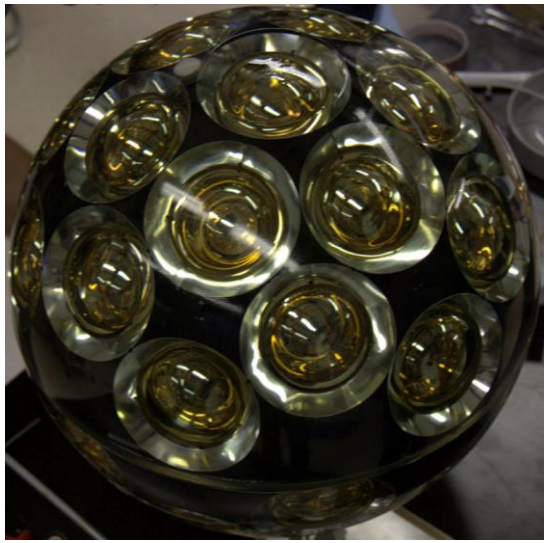
- Timing ≤2ns (RMS)
- QE ≥25-30%
- Collection efficiency ≥90%
- Photon counting purity 100% (by hits, ≤7)
- Price/cm2 ≤10” PMT

ETEL D792

Hamamatsu R12199

HZC XP53B20





Segmented cathode area: 31 x 3” PMTs

- Directional Sensitivity
- Photon Counting

Light concentrator ring

Cathode area: ~ 3 x 10-inch PMT

- Less overhead

Custom low-power HV bases

LED, piezo, compass and tiltmeter inside

PMT Time-over-Threshold measurements

FPGA readout

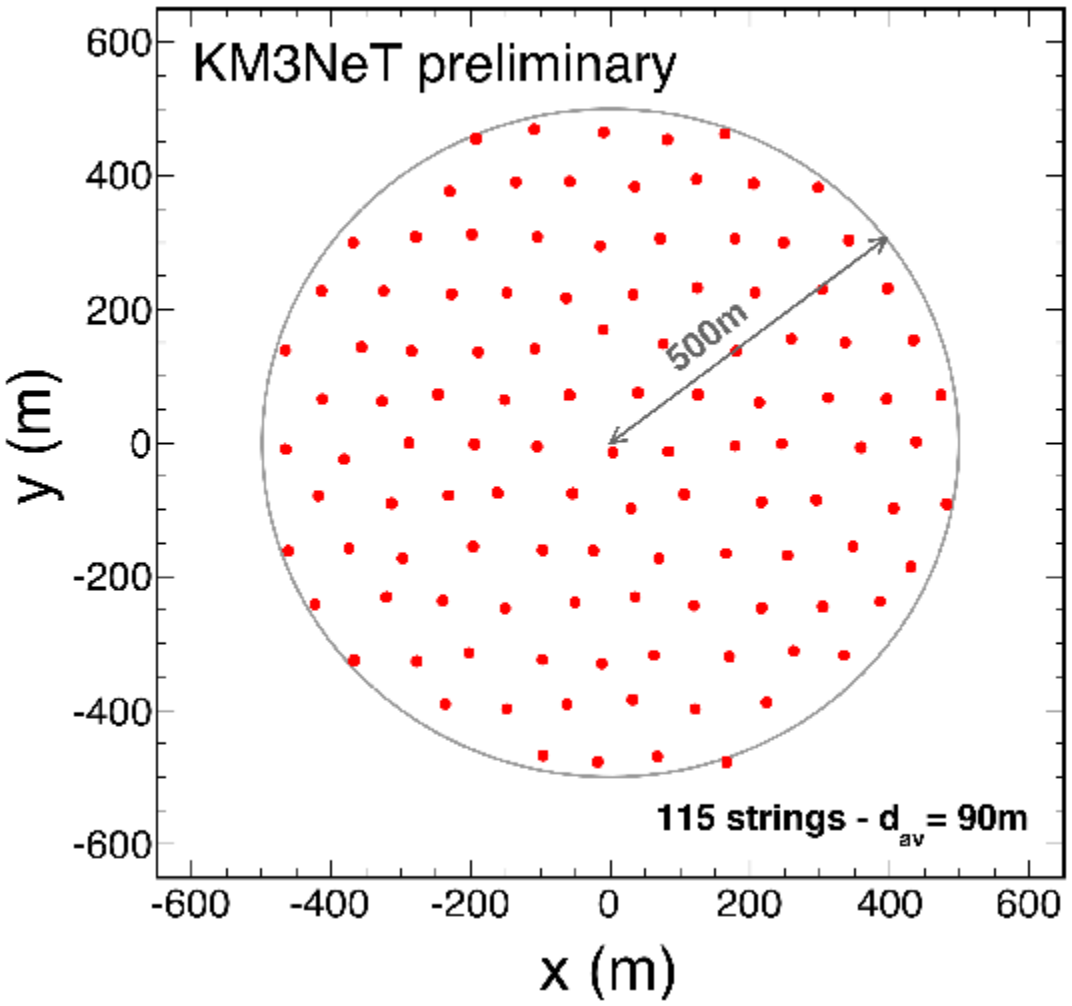
KM3NeT Design

Detection Units:

18 optical modules per vertical string
~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
Cost saving design

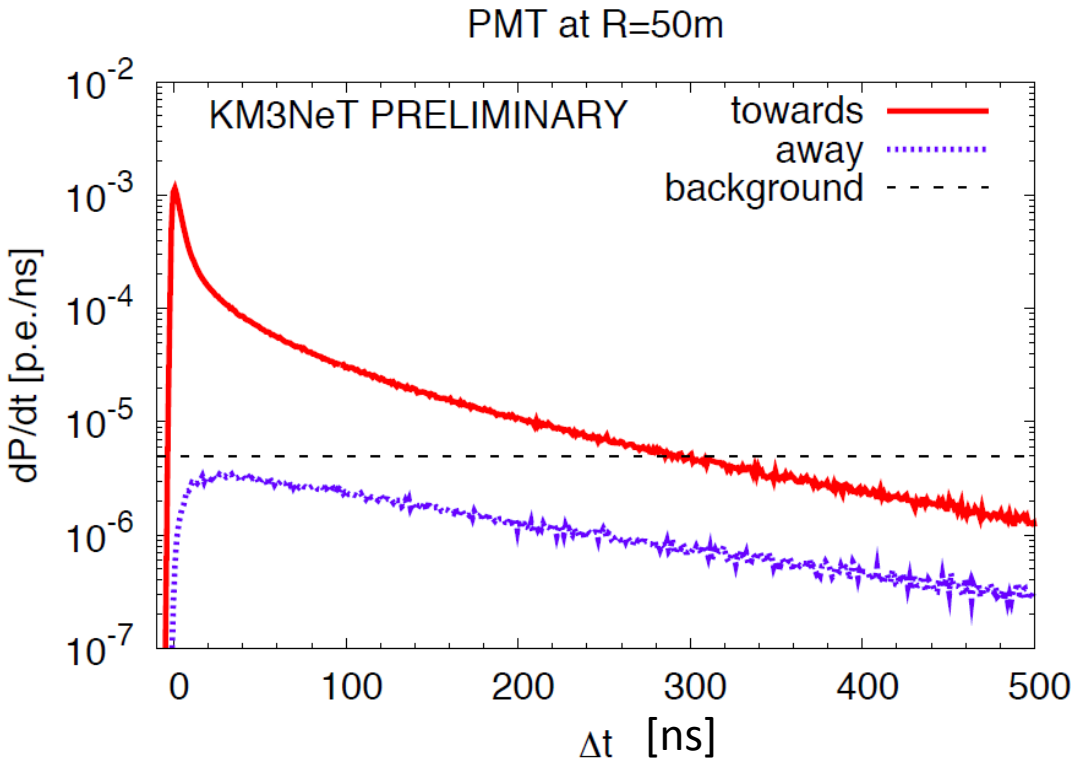
Infrastructure:

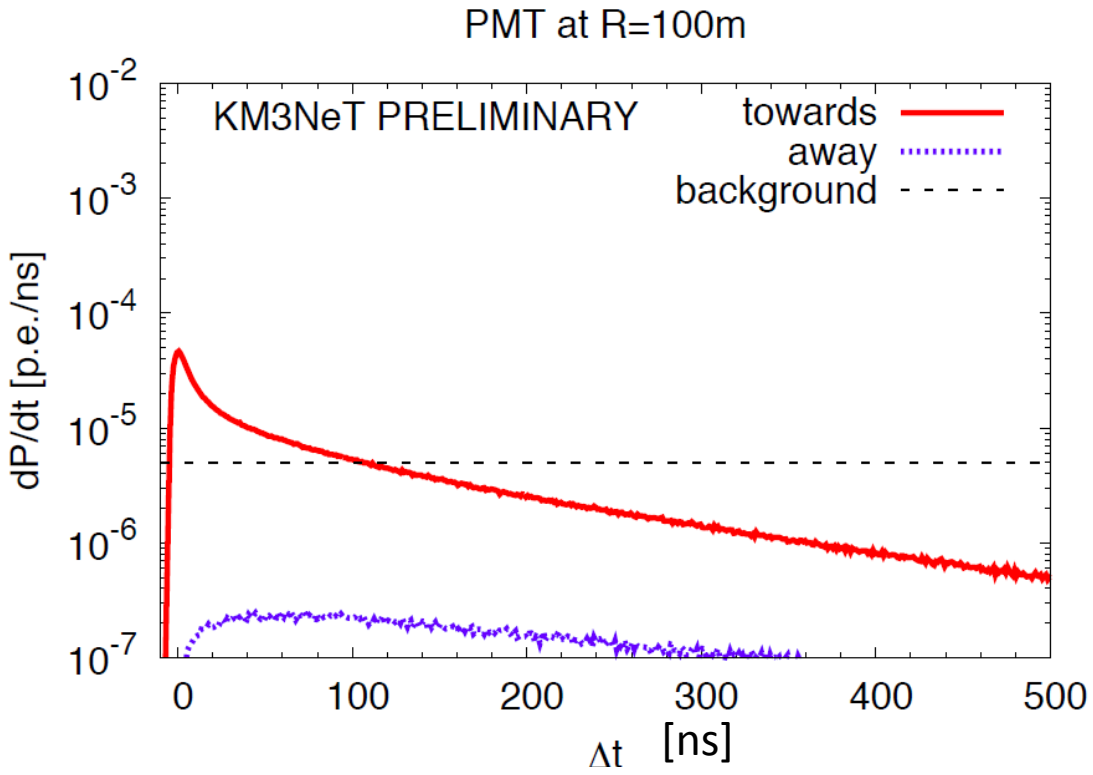
Building blocks of 115 strings
Sea-bed infrastructure
(facility for long term high-bandwidth connection for sea-science, biology etc.)
Optical data transmission
All-data-to-shore
Filtering/Trigger on-shore in computer farm



Photon arrival times (PDFs)

Mediterranean Sea Water:
L_{abs} ~60-100 m
L_{scat} ~50-70m



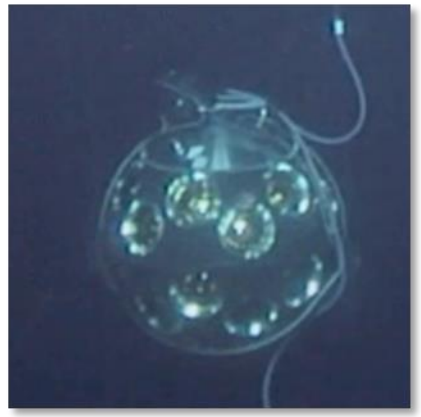


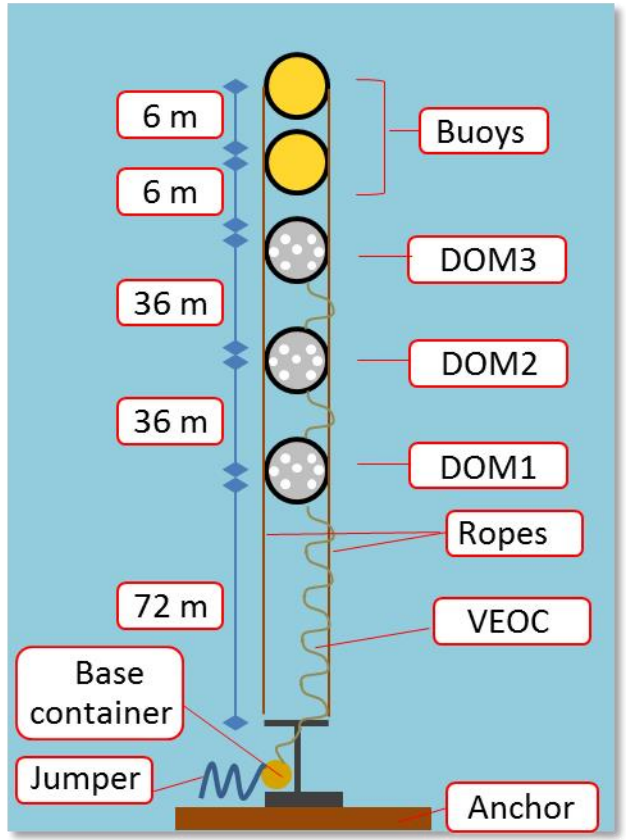
Angular resolution O(0.1°) can be reached

(Antares demonstrates and succesfully exploits the good angular resolution)

PPM DOM/DU

PPM-DOM: A prototype DOM on an Antares line (2500 m)
Operational since april 2013
Eur. Phys. J. C (2014) 74:3056

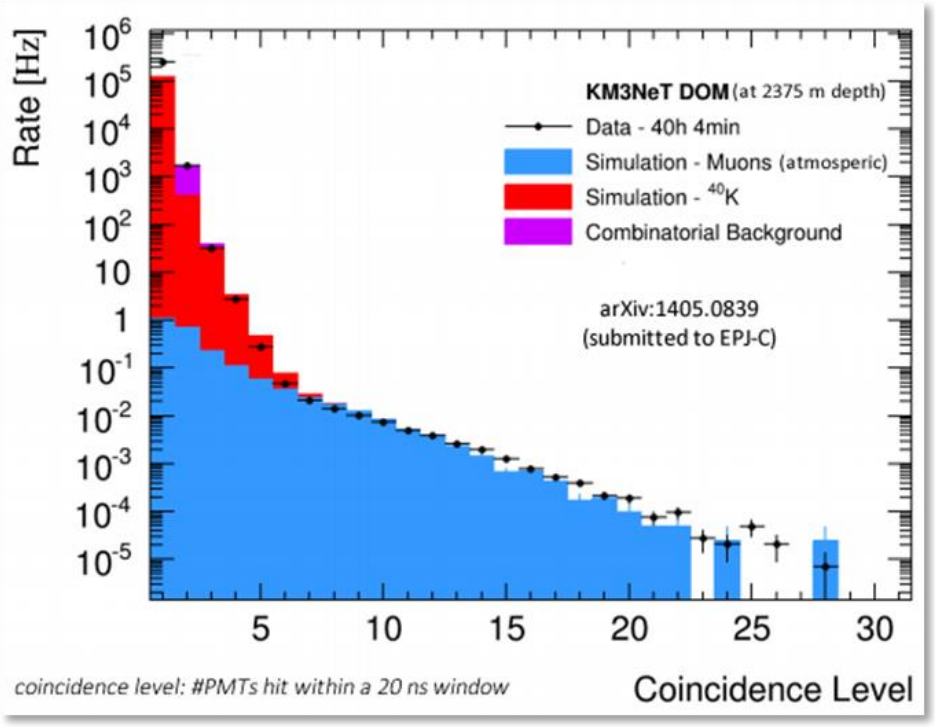




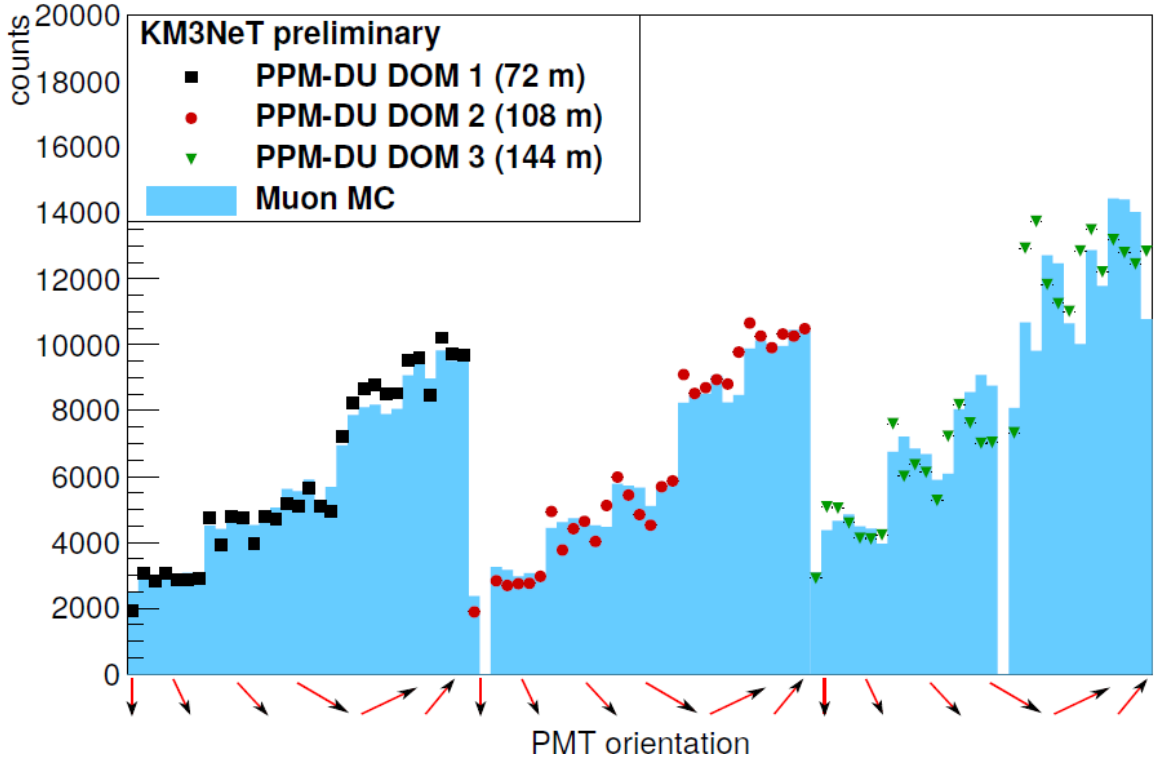
PPM-DU: A detection unit consisting of 3 DOMS deployed at Capo Passero (3500 m)
Operational since May 2014

PPM-DOM and PPM-DU results

Results from the PPM-DOM and PPM-DU validate the DOM design and prove the physics potential



Photon counting



Directional sensitivity at DOM level

(selected > 7 coincidences)

Phase-1 / DU-1

DU-1 : First full KM3NeT line

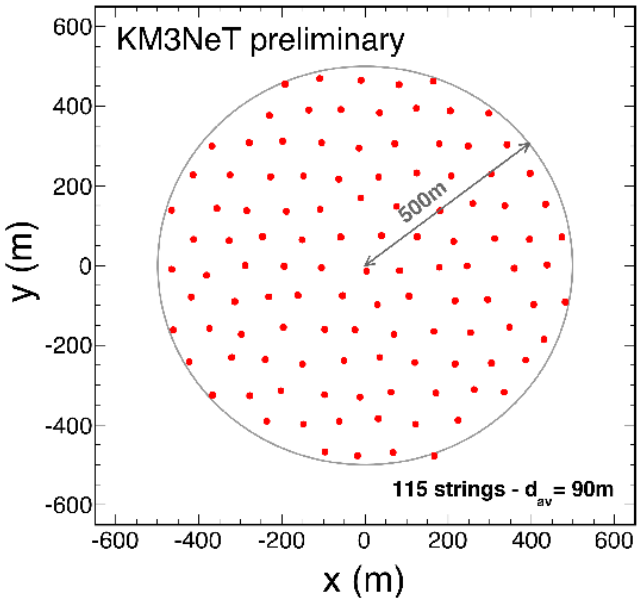
Assembled at the end of last year

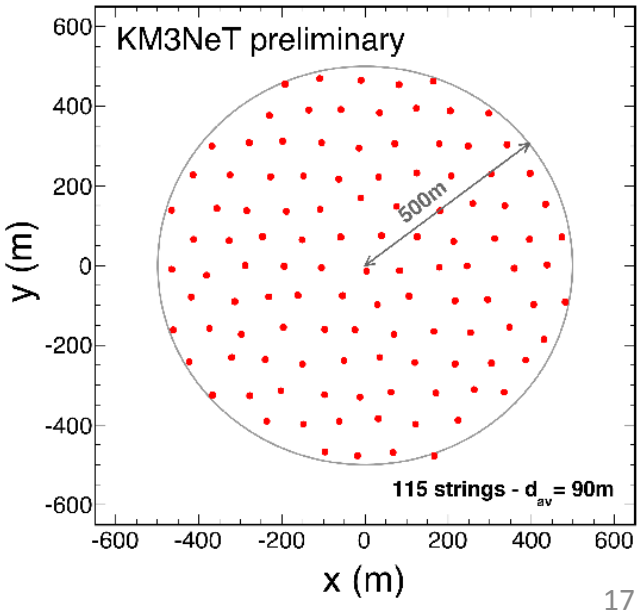
Currently being prepared for deployment in June at KM3NeT-France site

Phase- 1 completion by end 2016
24 lines at KM3NeT-Italy site
6 more "ORCA-style" (reduced length scales) lines at KM3NeT-Fr

The Future – ARCA (&ORCA)

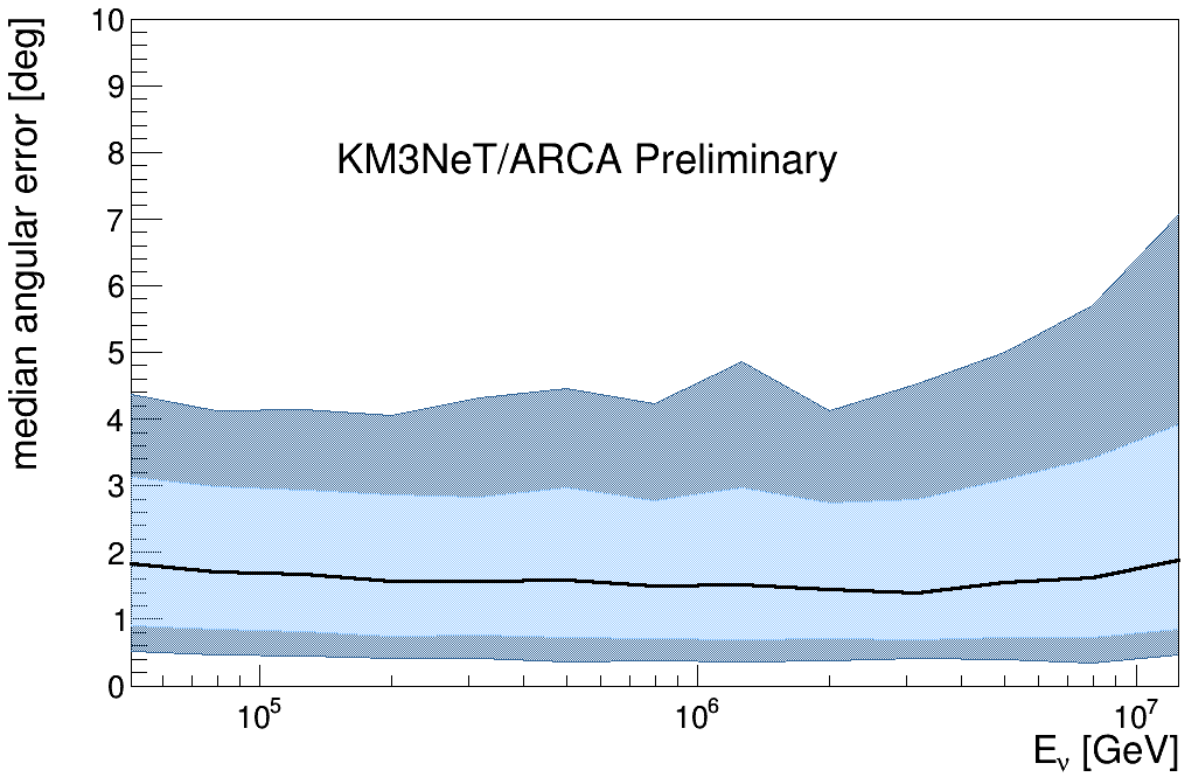
- 2 Building blocks
- ~IceCube size
- *High-resolution study of IceCube neutrino signal*
- Letter of Intent

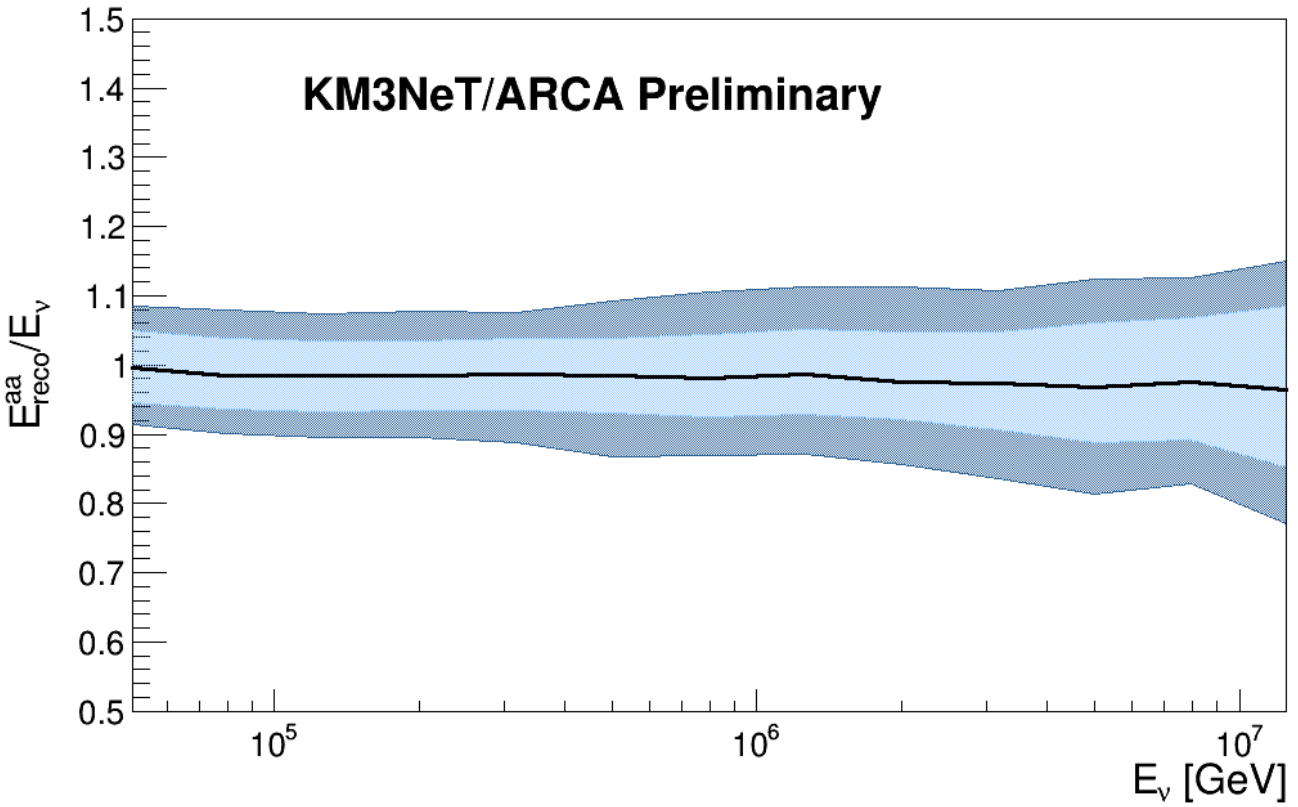




Cascades - Resolution

Cascade reconstruction uses photon counting capabilities of the DOMs



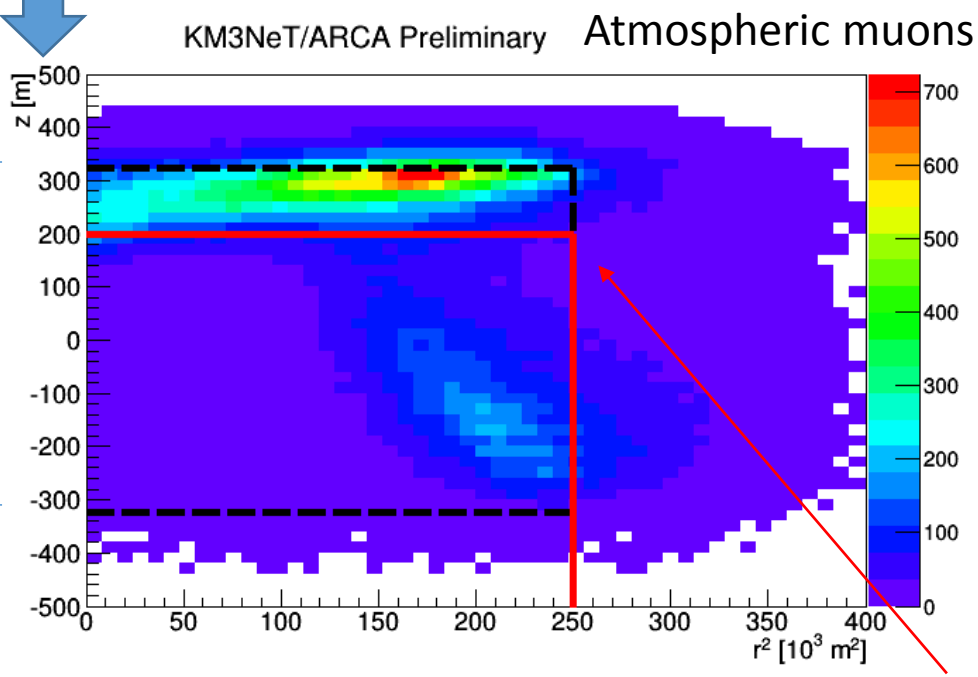


(Antares shower resolution is similar)

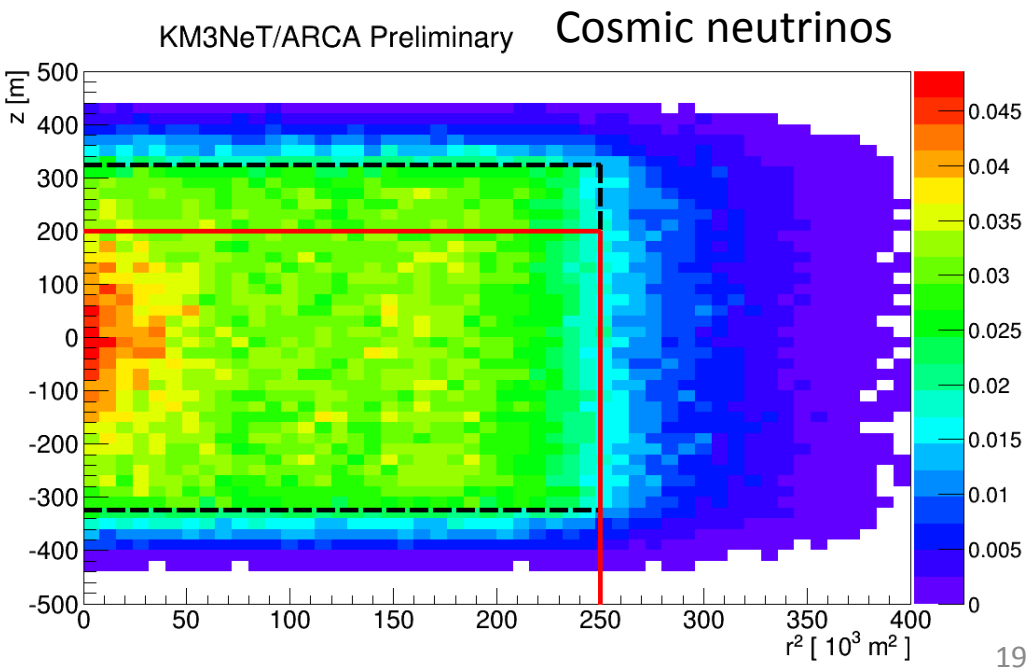
Cascade Analysis V1 – cut and count

1. Online data filter: ≥ 5 coincidences between PMTs in same optical module (ΔT=10 ns)
2. Event filter: number of hits ≥ 2000
3. Vertex cut: veto atmospheric muons
4. Energy cut: total time-over-threshold ≥ 12 μs
5. MRF/MDP cut: 2D-cut based on Boosted Decision Tree & energy estimate

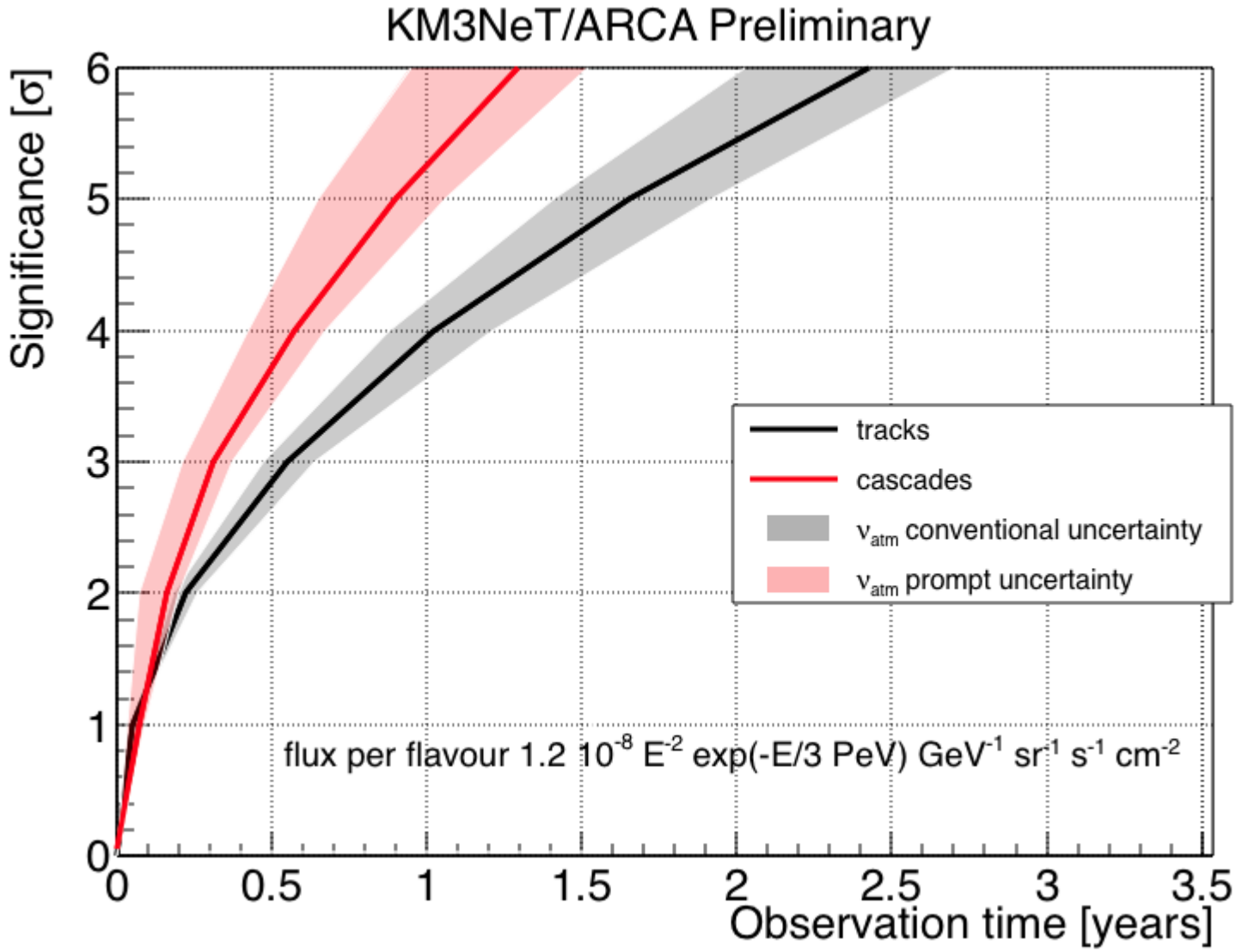
Detector volume



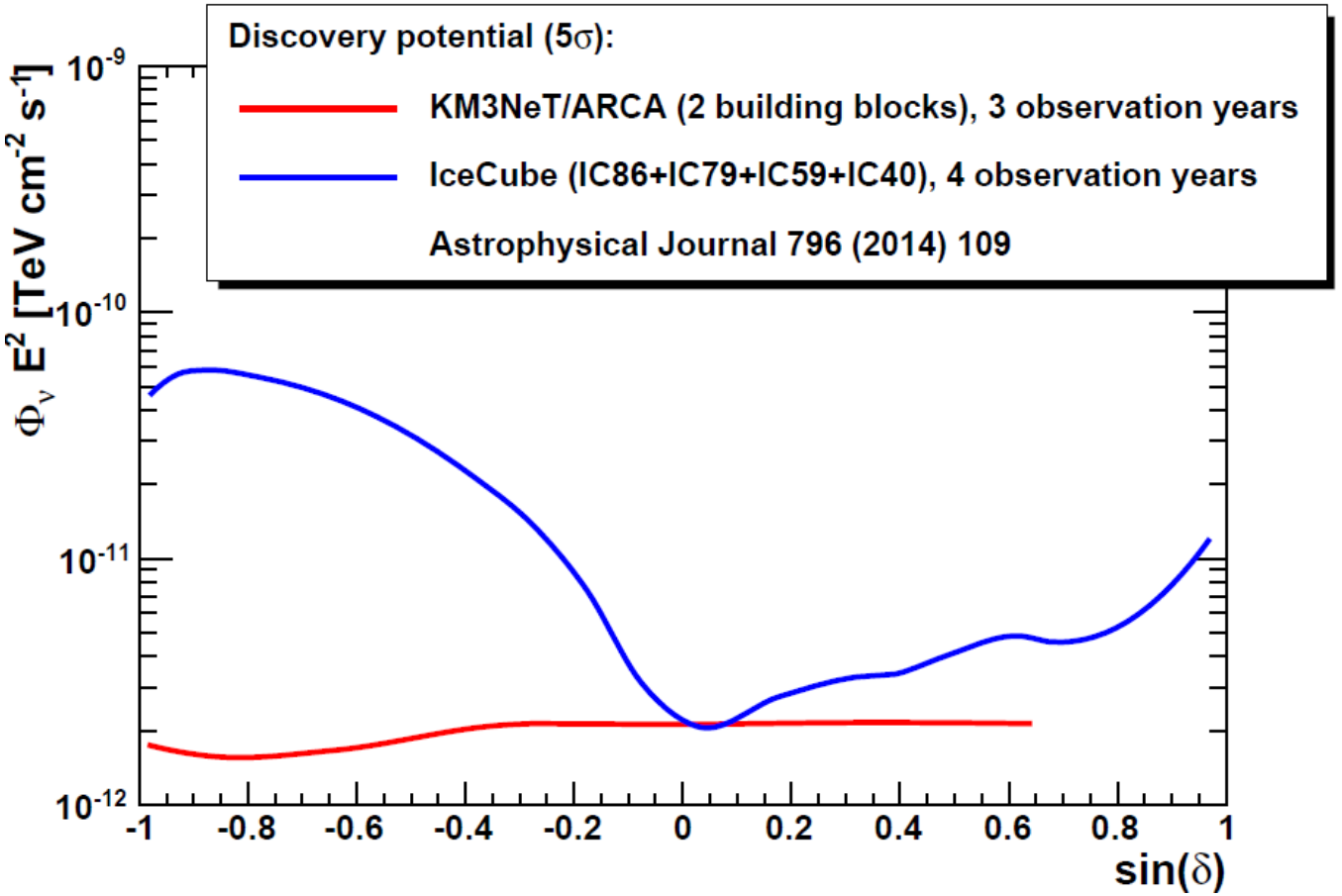
Vertex cut



ARCA Sensitivity – Diffuse Neutrino Flux



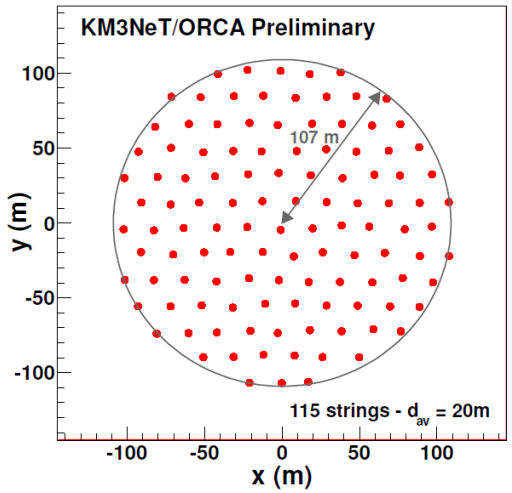
ARCA Sensitivity – E^{-2} Point source



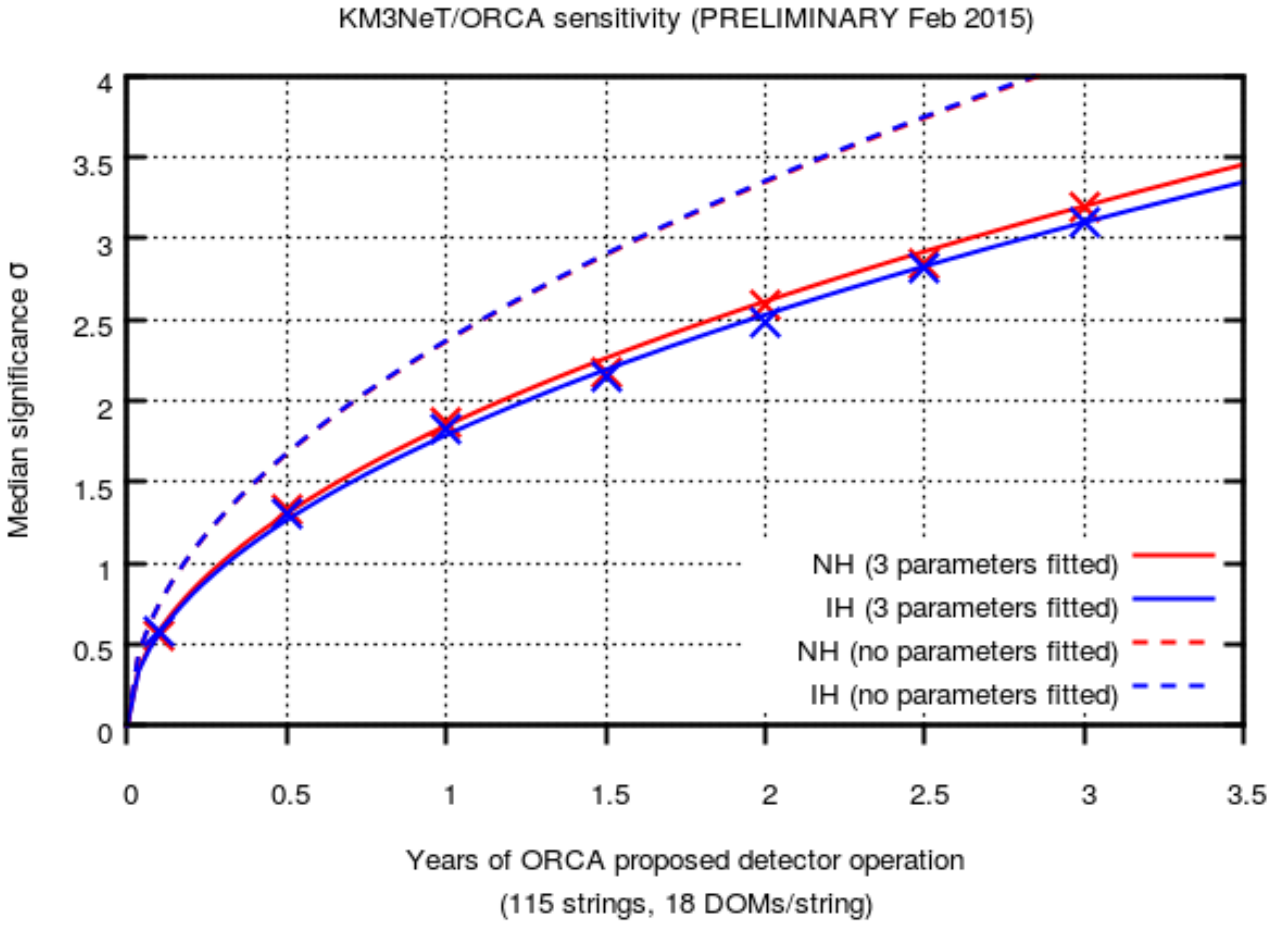
ORCA:
Neutrino physics using KM3NeT technology

Measurement of neutrino hierarchy using KM3NeT technology

Proposed ORCA detector
Scaled down version of KM3NeT building block :
6 m vertical spacing
20 m horizontal distance

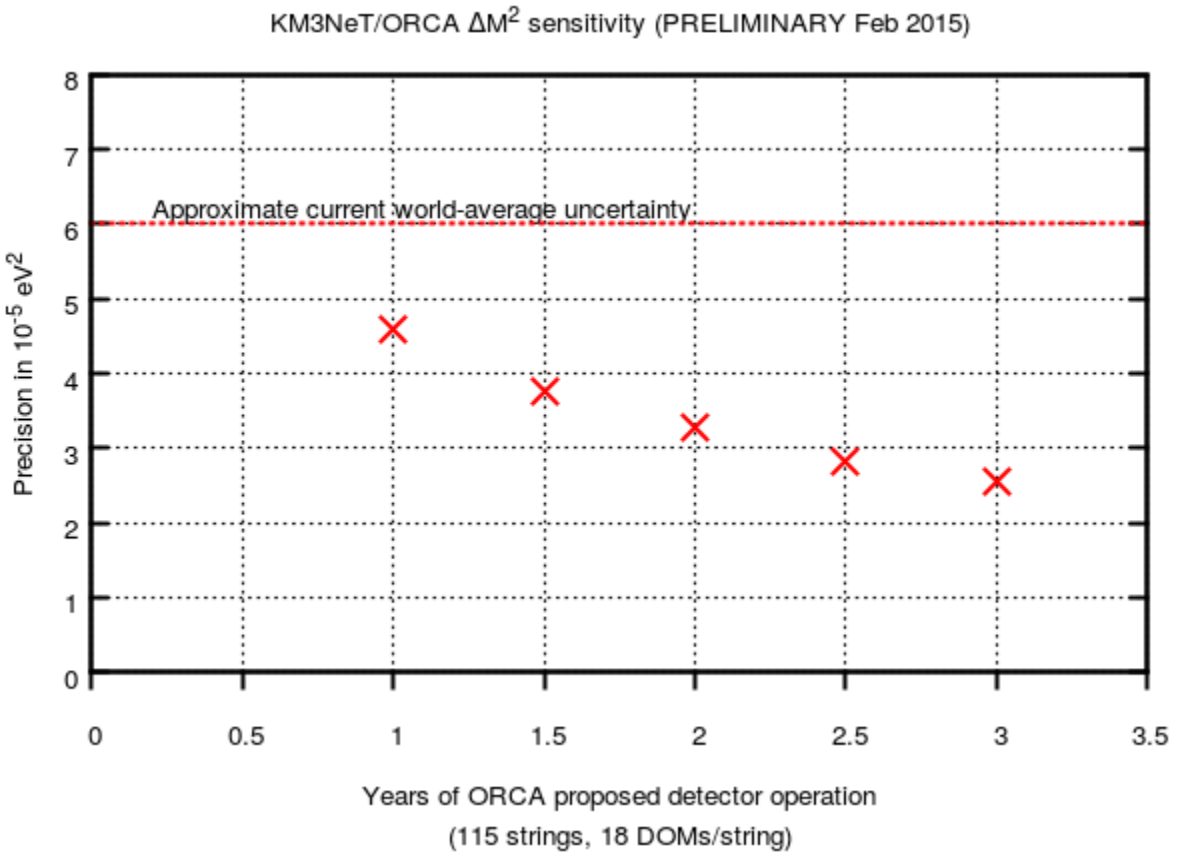


In the context of KM3NeT Phase-1:
6 ORCA strings by the end of 2016

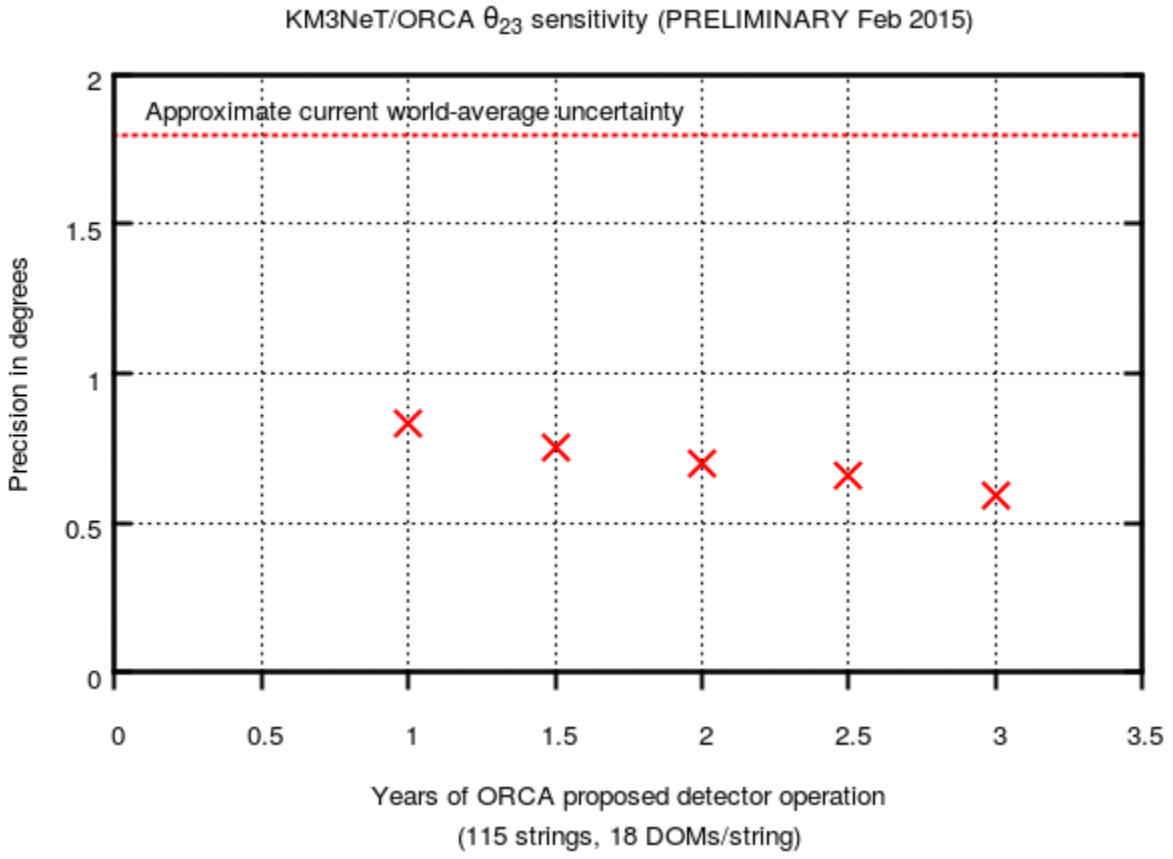


ORCA

ΔM^2



Θ_{23}



Summary

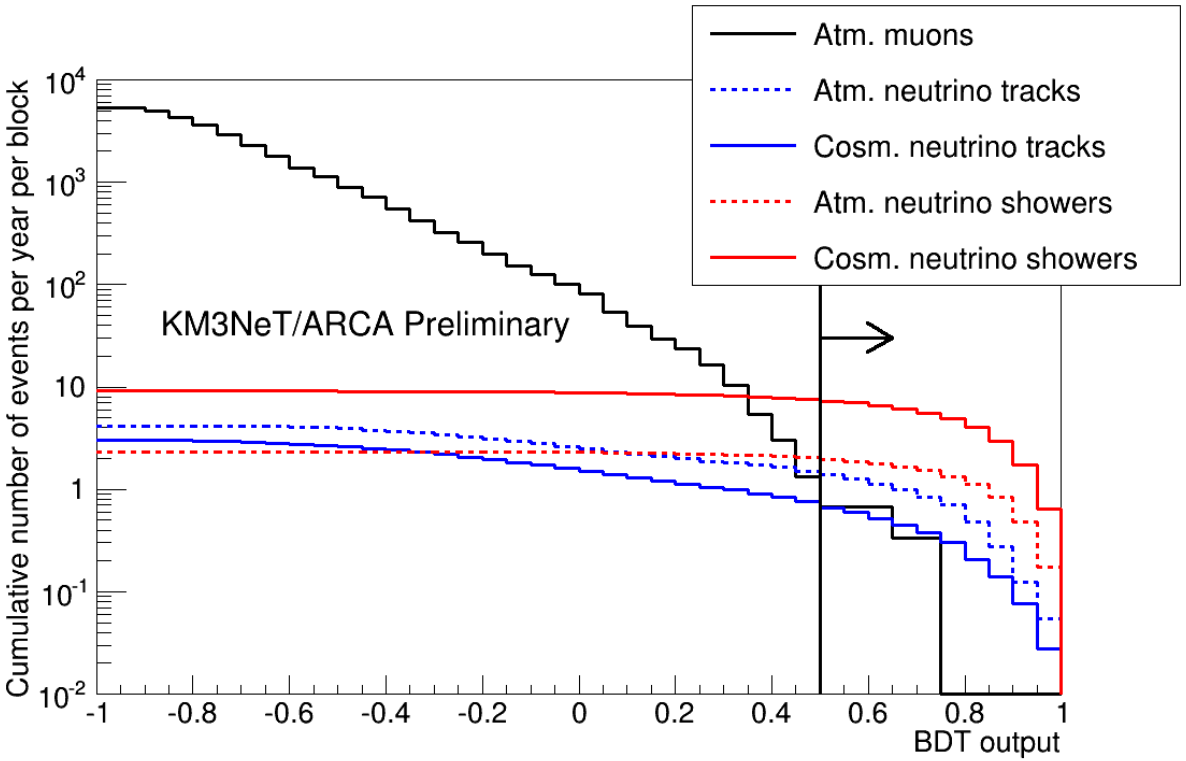
- Neutrino astronomy in the Mediterranean is making steady progress for about 2 decades
- Antares makes significant contributions to the understanding of the neutrino events detected by IceCube
- Antares will continue to provide interesting results while KM3NeT is being constructed
- The Mediterranean sea-water allows for a good angular resolution which will be exploited by the KM3NeT phases
- Results from KM3NeT prototypes validate design and prove physics potential
- KM3NeT Phase-1 construction ongoing
- ARCA:
  - Investigation of IceCube signal with different methodology, complementary field of view and improved resolution
  - all-flavour neutrino astronomy
- ORCA:
  - Using KM3NeT technology to investigate neutrino mass hierarchy

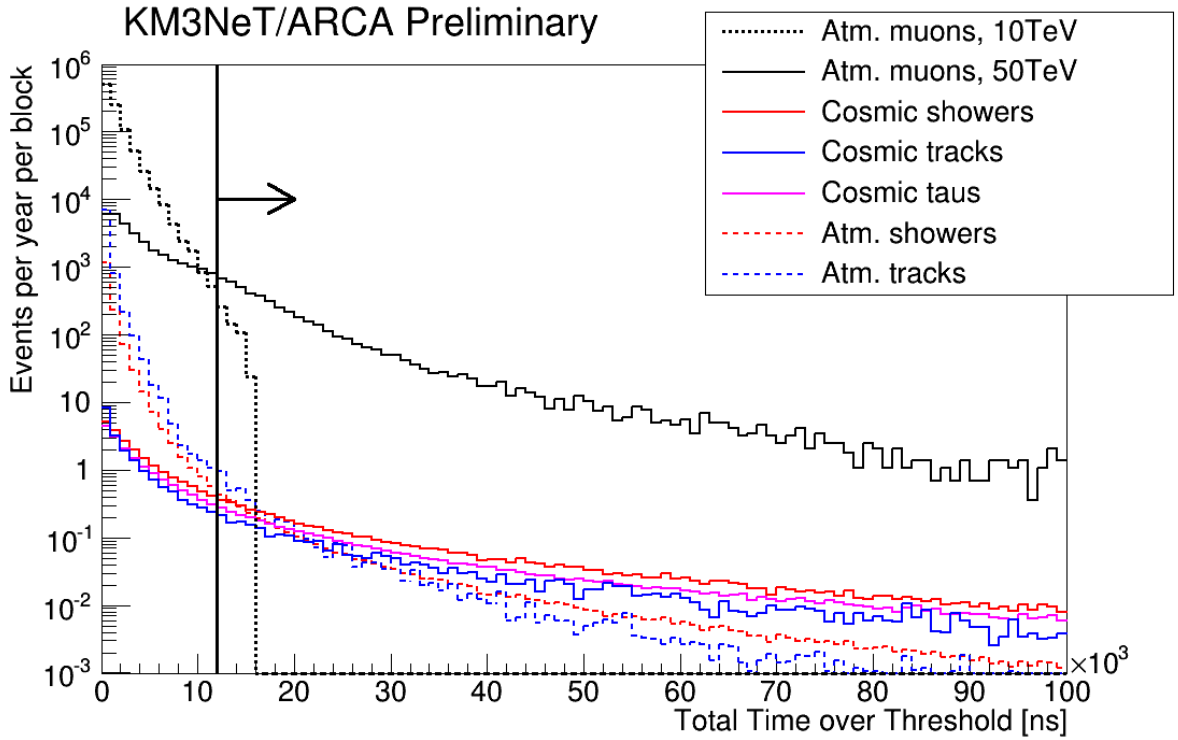
BACKUP

ORCA sensitivity

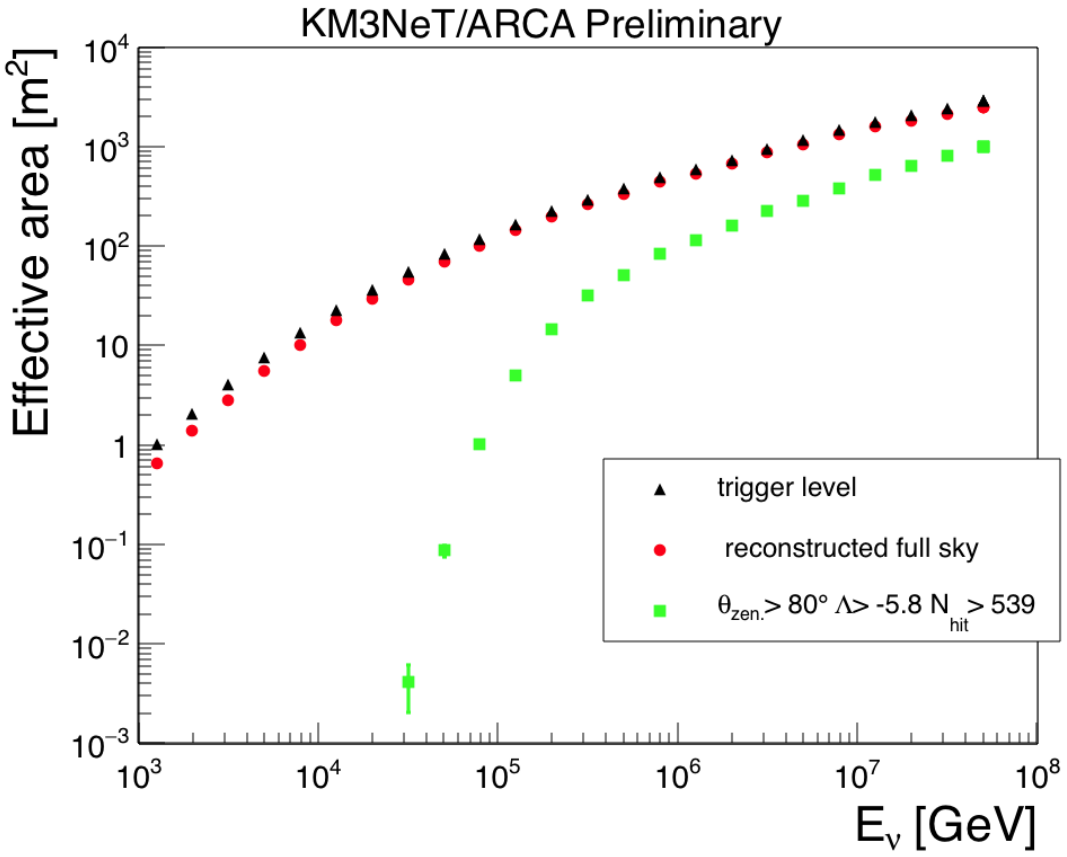
- Mass hierarchy hypothesis test employing likelihood ratio
- Likelihood fitting of ΔM2, θ23 and flux normalization
- Pseudo-experiments use
    - atmospheric neutrino flux (Frejus)
    - Neutrino cross sections (GENIE)
    - fixed set of oscillation parameters, δCP = 0
    - 3-flavour earth matter oscillations (checked against GLOBES)
    - track vs shower event classification
    - full MC detector efficiency / resolution response matrices
    - including misidentified and NC events
    - atmospheric muon contamination in track channel
    - neutral current event contamination

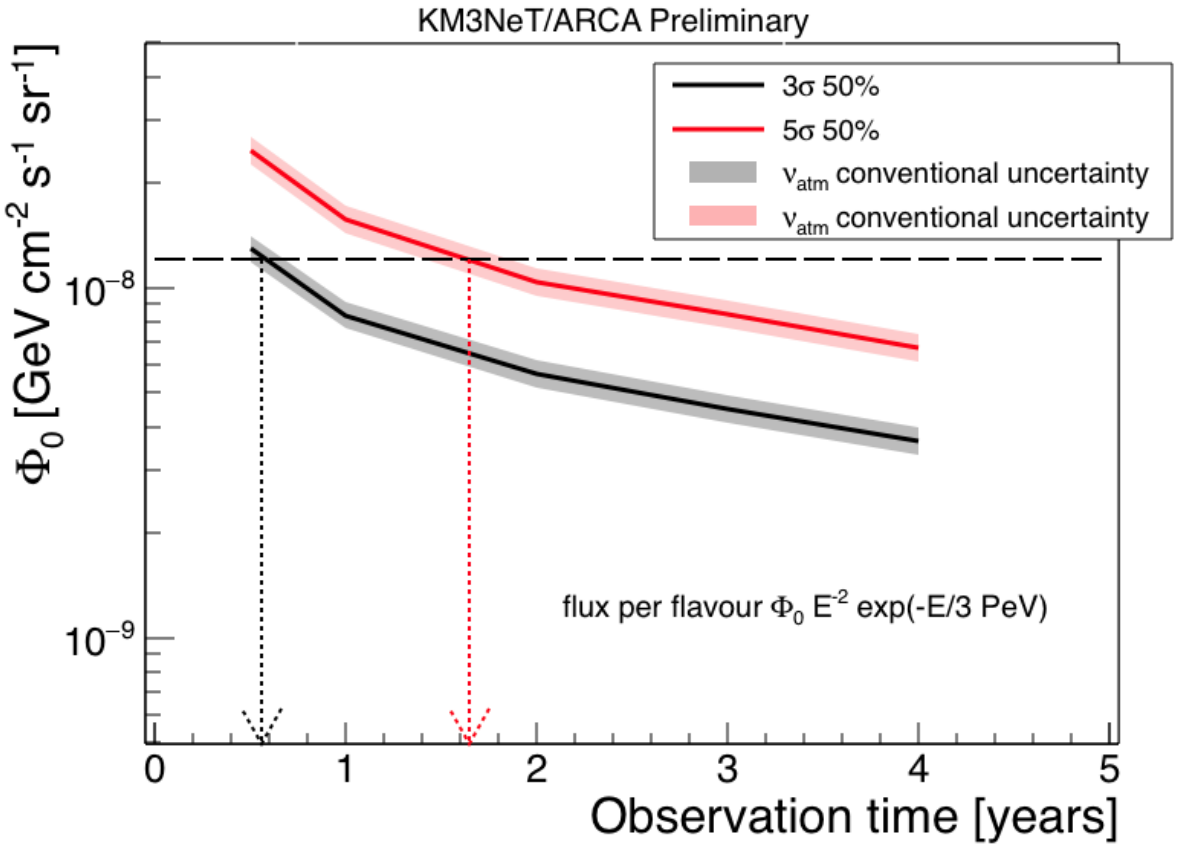
ARCA Cascade Analysis





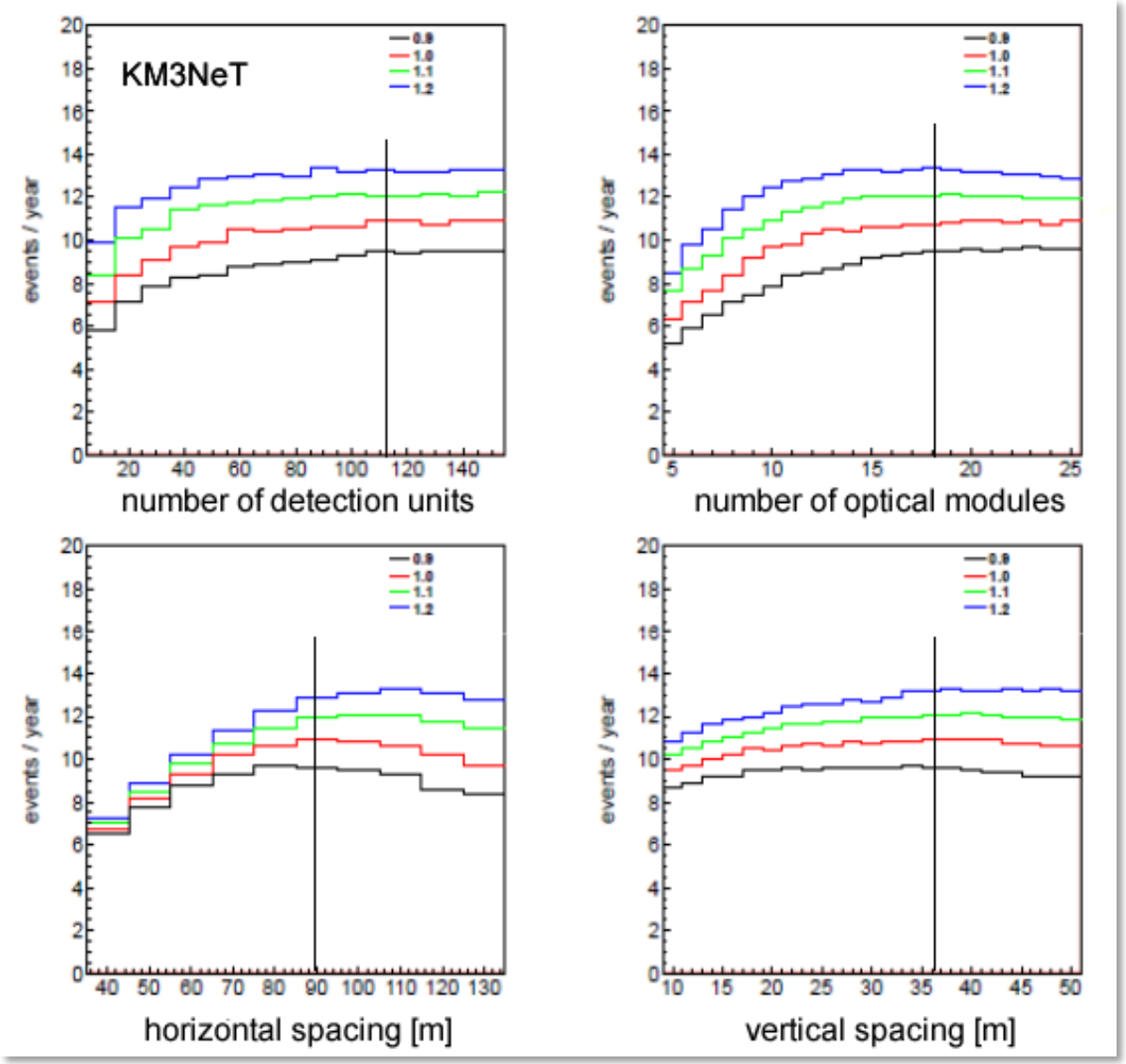
ARCA Diffuse Flux



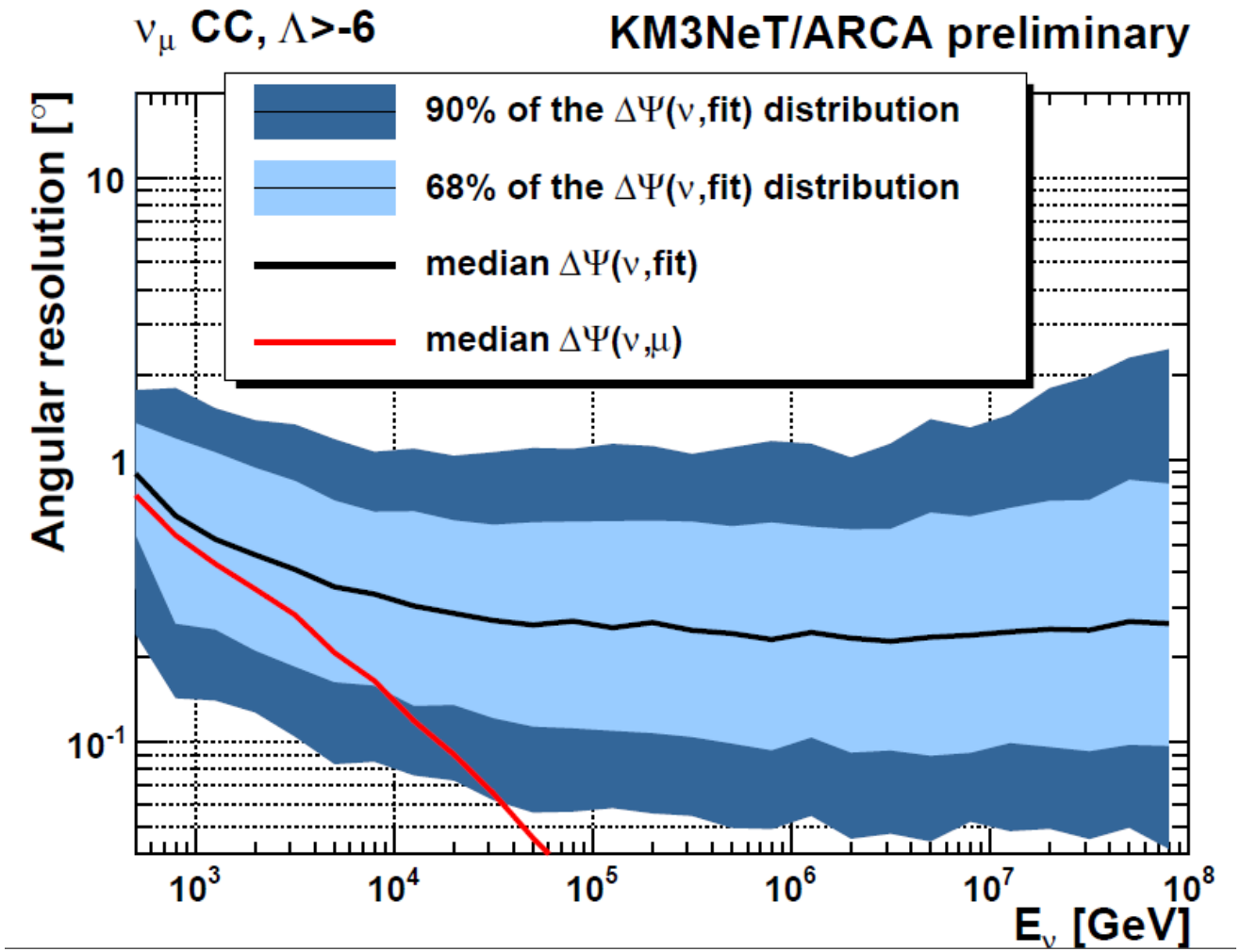


KM3NeT Detector optimization

For estimated
flux from RXJ1713…



Resolution - Muon

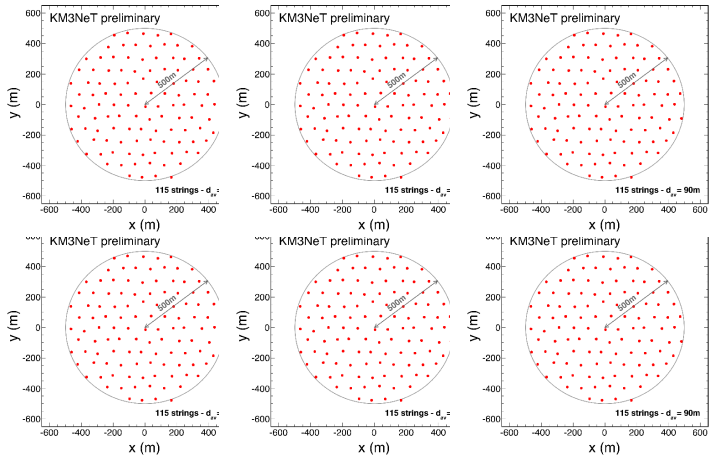


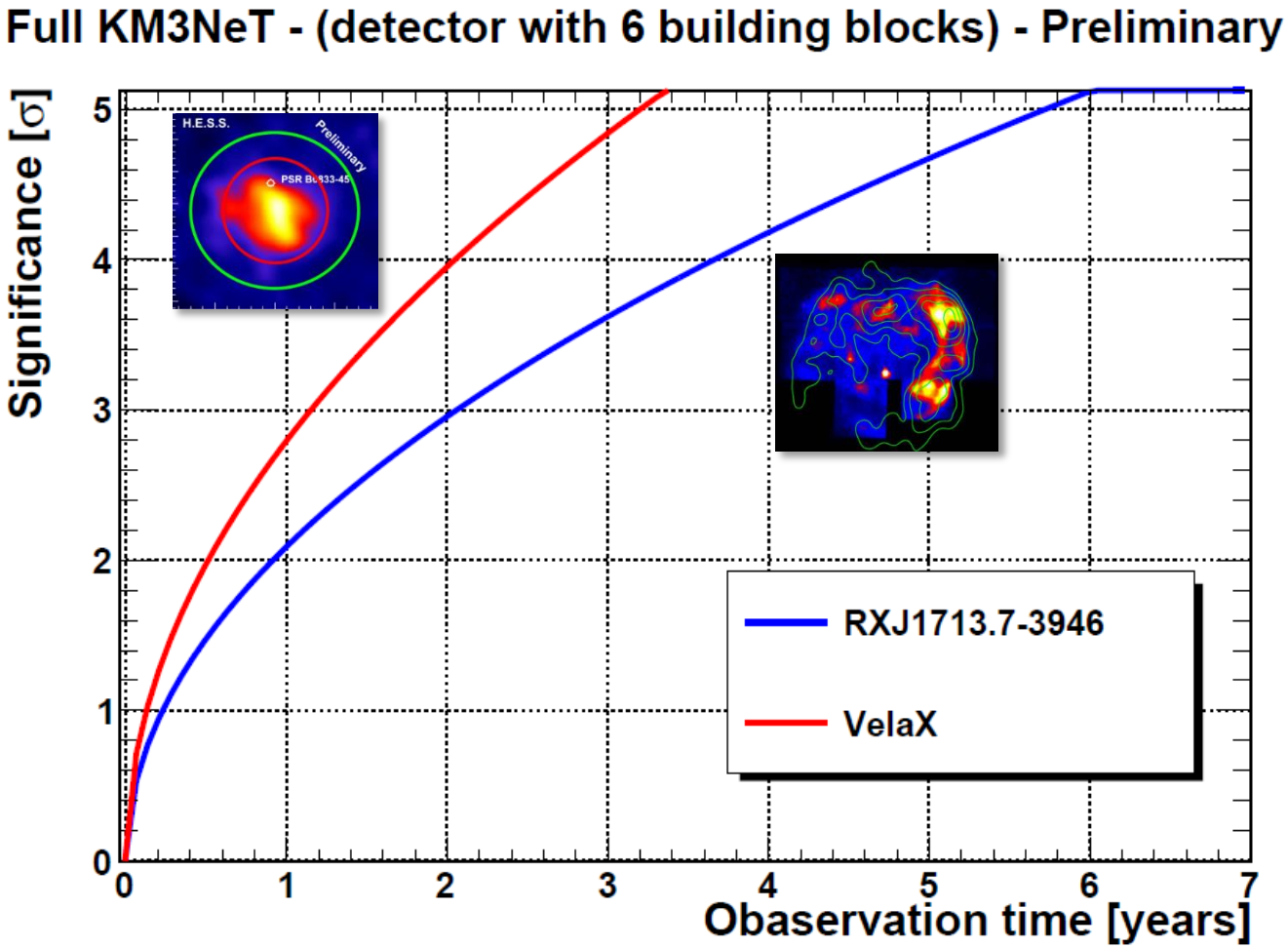
Further future – KM3NeT Phase 3

Neutrino astronomy – Galactic Sources

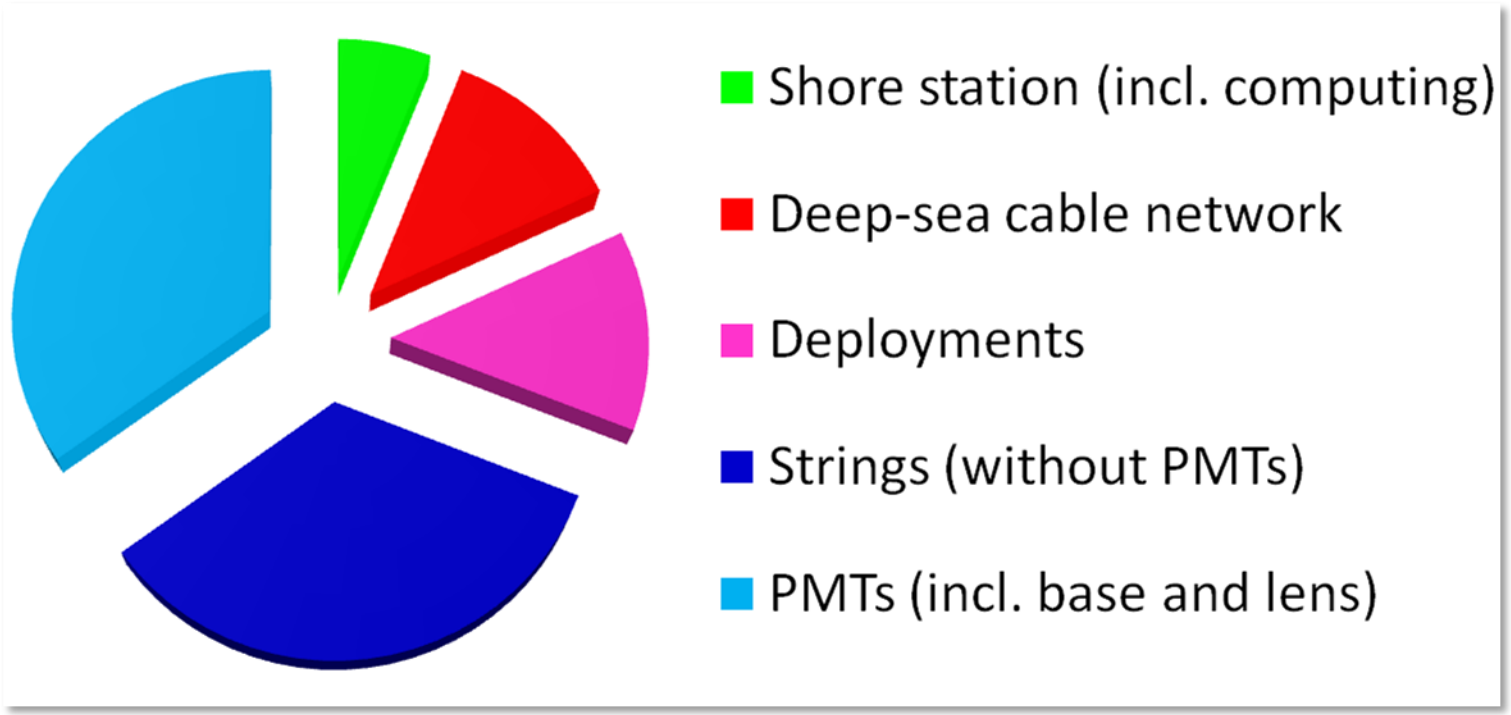
6 building blocks

3.5-6 km3 (depending on string spacing)





¶S.R. Kelner, *et al.*, Phys. Rev. D 74 (2006) 034018.
§F.L. Villante and F. Vissani, Phys. Rev. D 78 (2008) 103007.


Shore station (incl. computing)
Deep-sea cable network
Deployments
Strings (without PMTs)
PMTs (incl. base and lens)