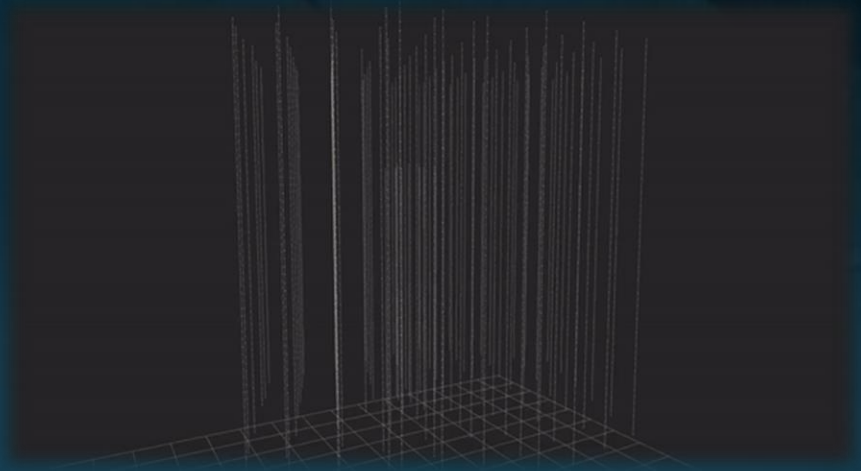
THE KM3NeT NEUTRINO OBSERVATORY

Life, Earth and Space Sciences



Prof. Dr. Harold Yepes Ramírez

KM3NeT-EC PRINCIPAL INVESTIGATOR

LASF4RI NATIONAL REPRESENTATIVE

SCHOOL OF PHYSICAL SCIENCES AND NANOTECHNOLOGY

UNIVERSIDAD YACHAY TECH

XVI ENCUENTRO DE FÍSICA

Desafíos Computacionales en la Física Contemporánea

Quito - Ecuador

ESCUELA POLITÉCNICA NACIONAL

QUITO –ECUADOR

25-29TH NOVEMBER 2019

OUTLINE

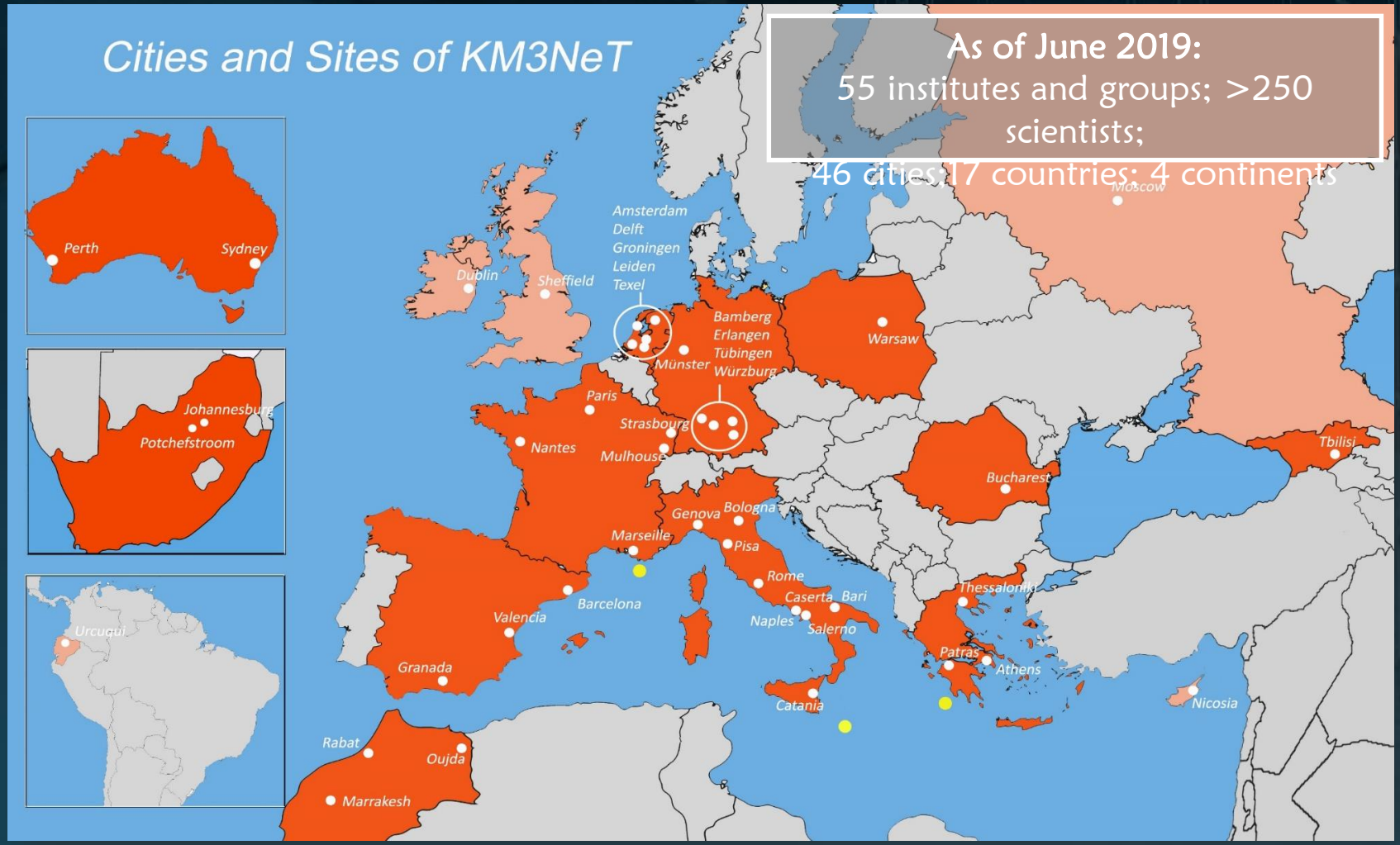
PART 1
THE KM3NeT SCIENCE

PART 2
THE KM3NeT NEUTRINO DETECTORS

PART 3
KM3NeT FIRST RESULTS (SELECTION)

PART 1
THE KM3NeT SCIENCE

THE KM3NeT COLLABORATION



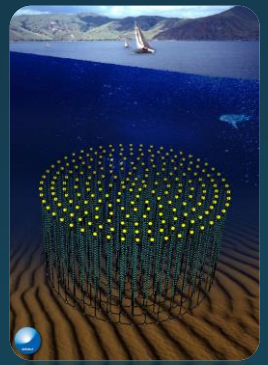
KM3NeT SCIENCE: LIFE AND EARTH SCIENCES

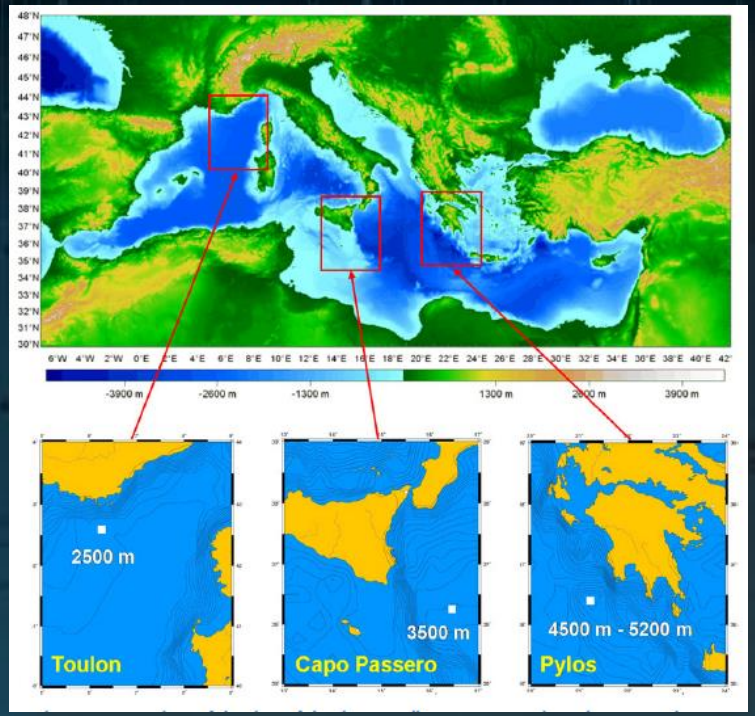
MOTIVATION:

Enhance the knowledge spanning Life, Earth, and Space Sciences (astro-particle physics), taking advantage of operational experience of “Neutrino Observatories”.

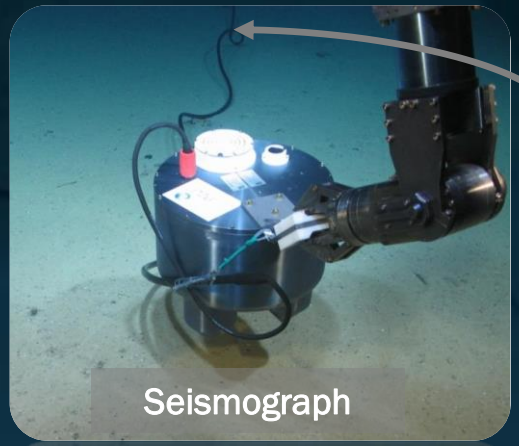
OBJECTIVE (LIFE AND EARTH SCIENCES):

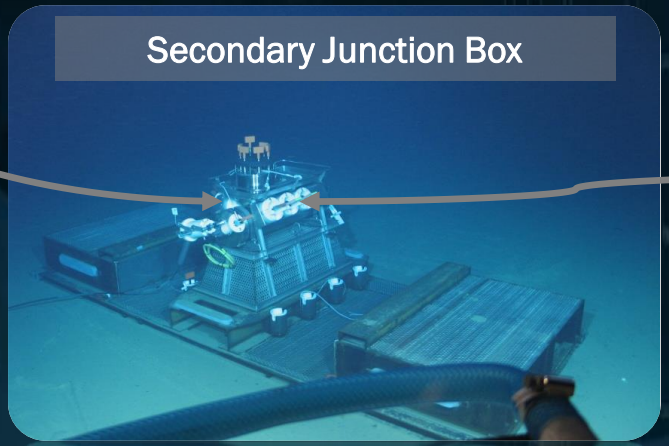
Mediterranean deep-sea as of prime interest for marine bio- and geo-science investigations: permanent, real-time and high-bandwidth connection to shore.

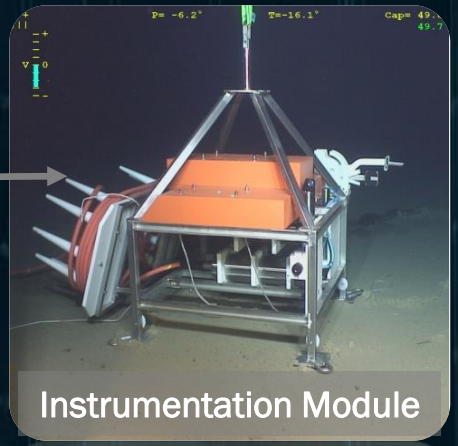


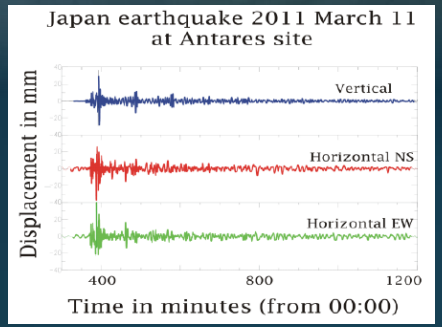


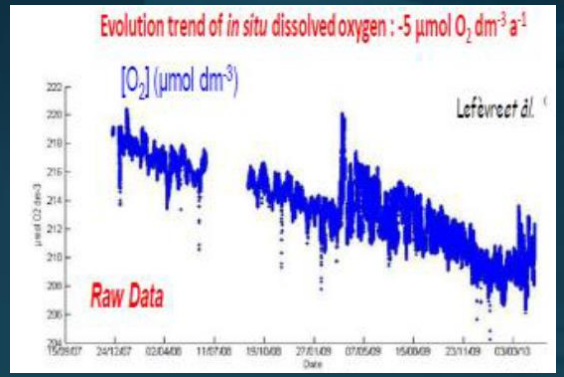
KM3NeT SCIENCE: LIFE AND EARTH SCIENCES

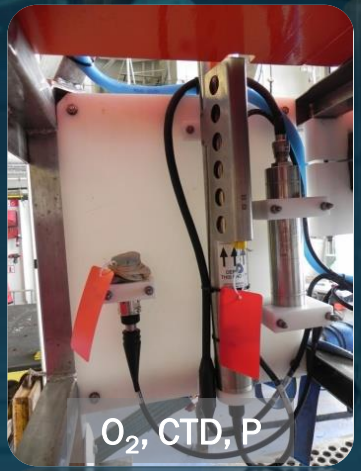












Deep Ocean Cabled Observatories Workshop ...
https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=165389

KM3NeT SCIENCE: LIFE AND EARTH SCIENCES

Key points for Life and Earth Sciences with KM3NeT:

- ✓ Complementary goals and collaborative activities with an infrastructure hosting **multi-cubic-kilometer neutrino telescopes**.
- ✓ Infrastructure as a world leading observatory with enormous discovery potential, important node in a global network of deep-sea observatories:

KM3NeT

ESONET NOE

emso ERIC EUROPEAN RESEARCH INFRASTRUCTURE CONSORTIUM

GMES Observing our planet for a safer world

NEPTUNE Canada Transforming Ocean Science

OOI OCEAN OBSERVATORIES INITIATIVE

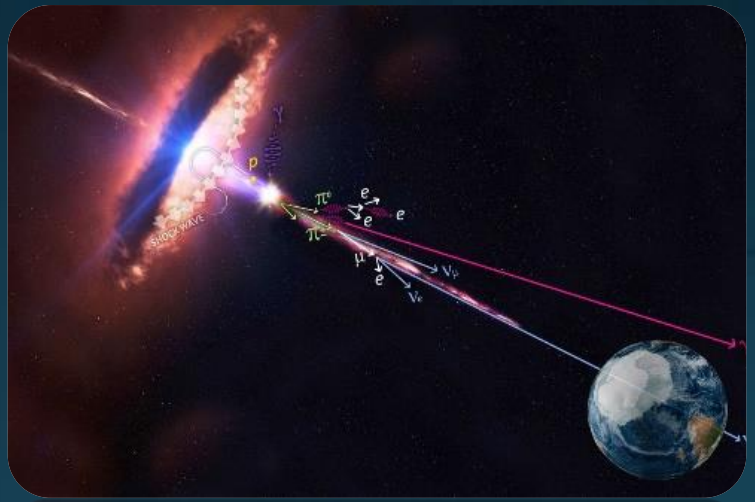
+ DONET (Japan)

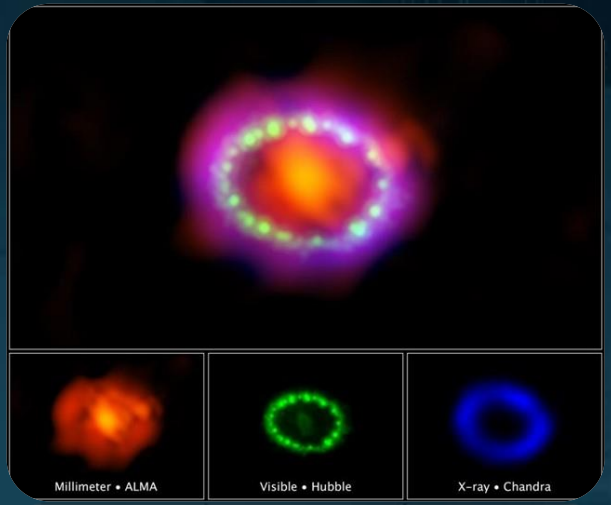
KM3NeT SCIENCE: ASTROPARTICLE PHYSICS

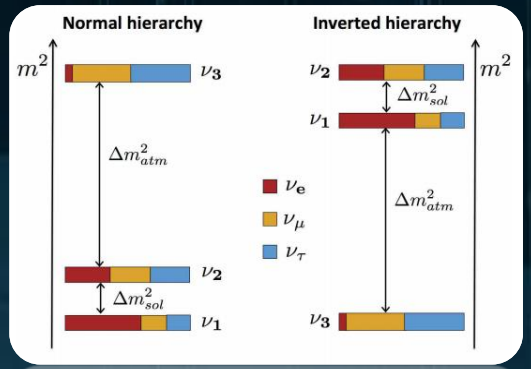
OBJECTIVES (ASTRO-PARTICLE PHYSICS):

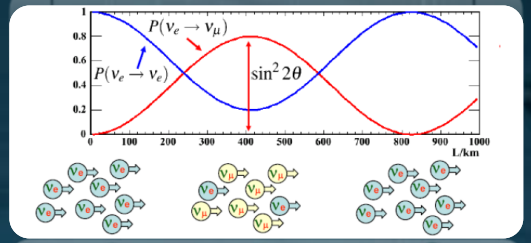
Astrophysical Neutrinos

IceCube signal (TXS Blazar), discovery and subsequent study of other high-energy neutrino sources in the Universe.









Atmospheric Neutrinos

Neutrinos Mass Hierarchy (NMH), neutrino oscillation parameters, tau-neutrino appearance.

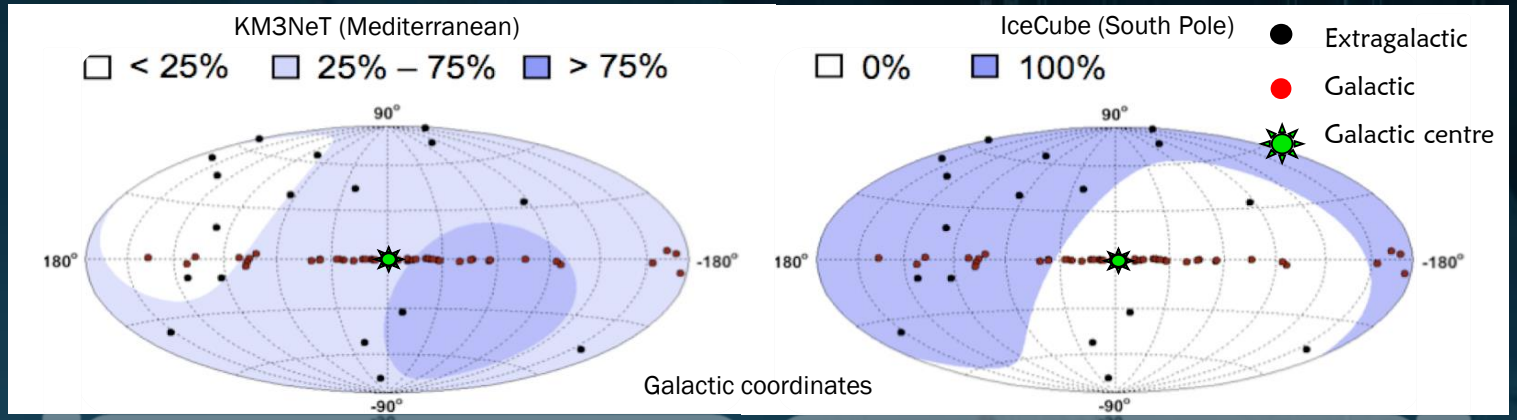
KM3NeT SCIENCE: ASTROPHYSICAL NEUTRINOS

A km^3 telescope in the Mediterranean (North Hemisphere) means:

Full sky coverage.

Visibility of Galactic Plane + Galactic Center.

1.5 sr common view per day.



Detection media: water vs Ice

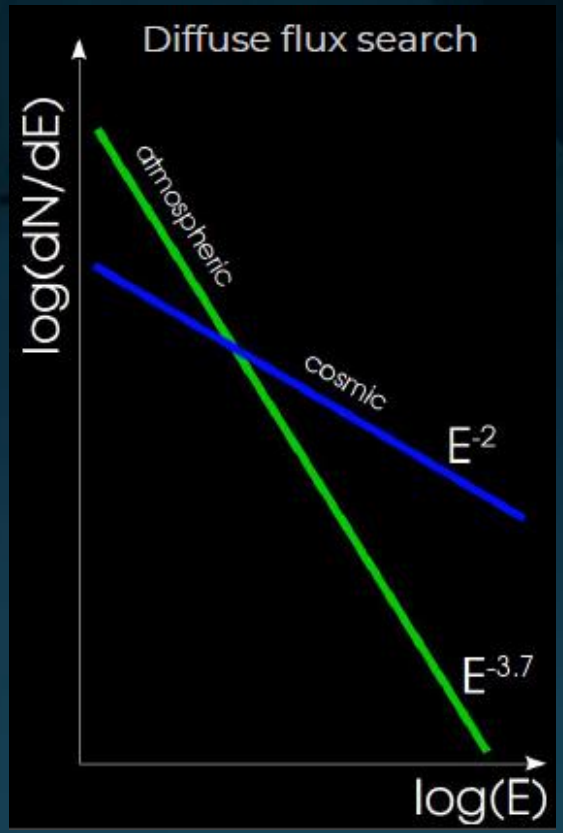
In ice less light absorption → better energy reconstruction.

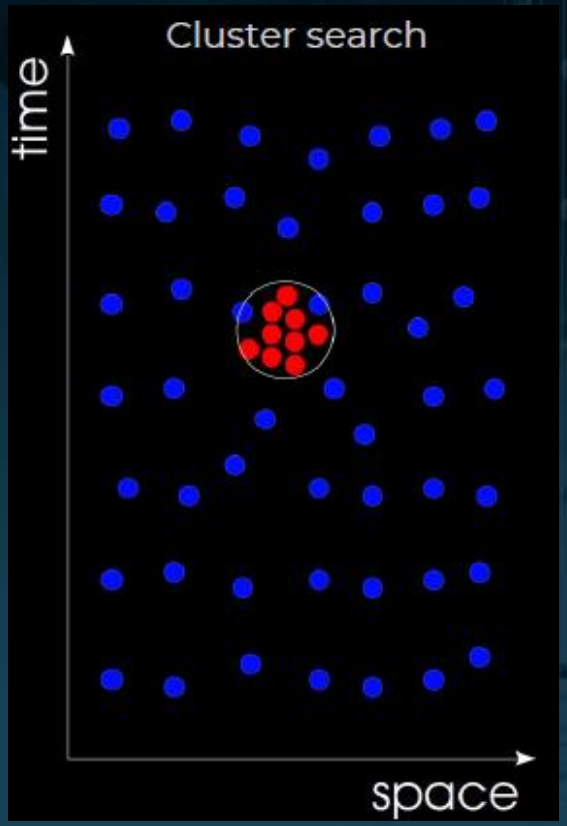
In water less scattering → better pointing accuracy (point source identification).

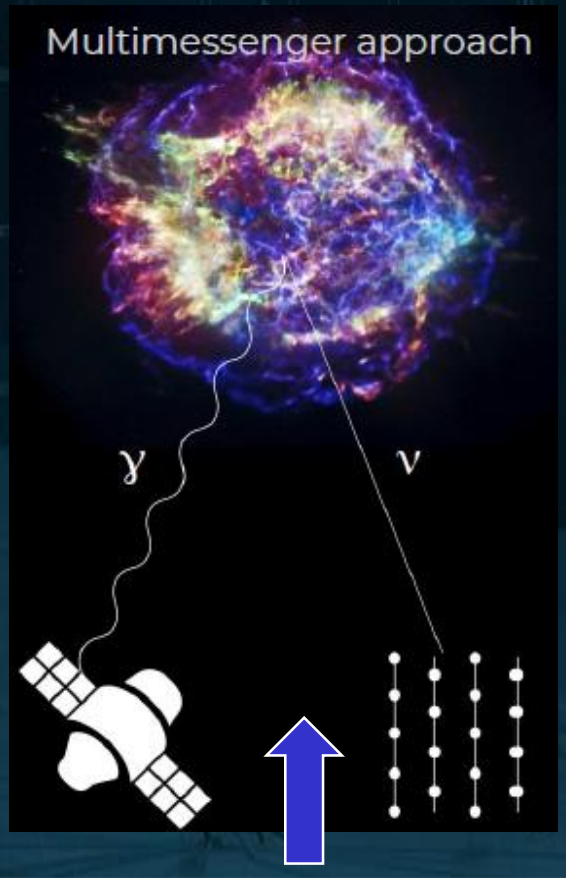
In seawater → ^{40}K optical background requires causality filters but useful for calibration.

See poster by J.D. Alcivar-Espin in this event!

KM3NeT SCIENCE: ASTROPHYSICAL NEUTRINOS





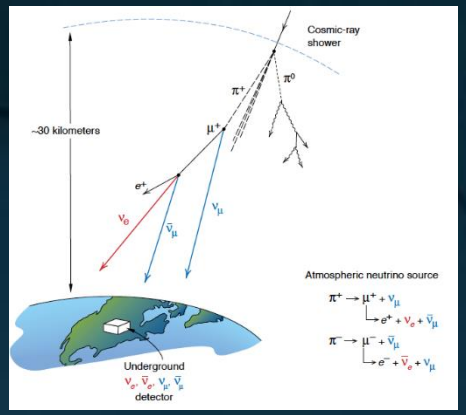


See talk by Jonathan Quirola in this event!

Credits to Rodrigo G. Ruiz, Nikhef, KM3NeT at Lake Louise Winter Institute 2019

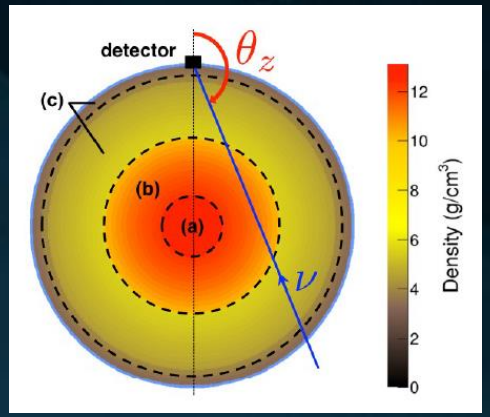
KM3NeT SCIENCE: ATMOSPHERIC NEUTRINOS

Atmospheric ν-flux



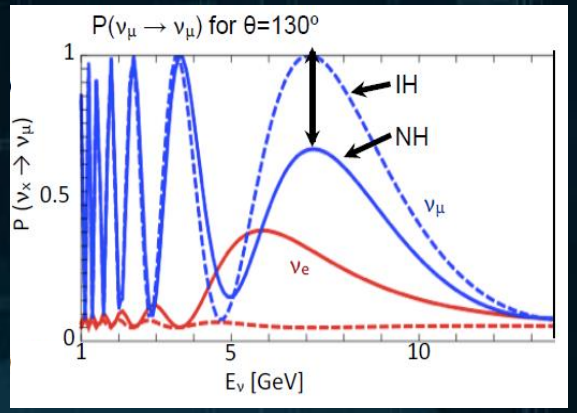
Known composition of ν_μ , ν_e

ν-propagation through Earth

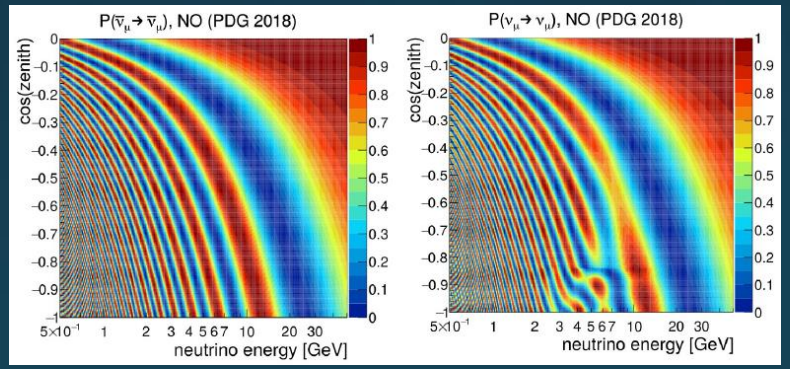


Wide range of SBL-LBL (50-12742 km) and E_ν (GeV → PeV)

ν-oscillation pattern



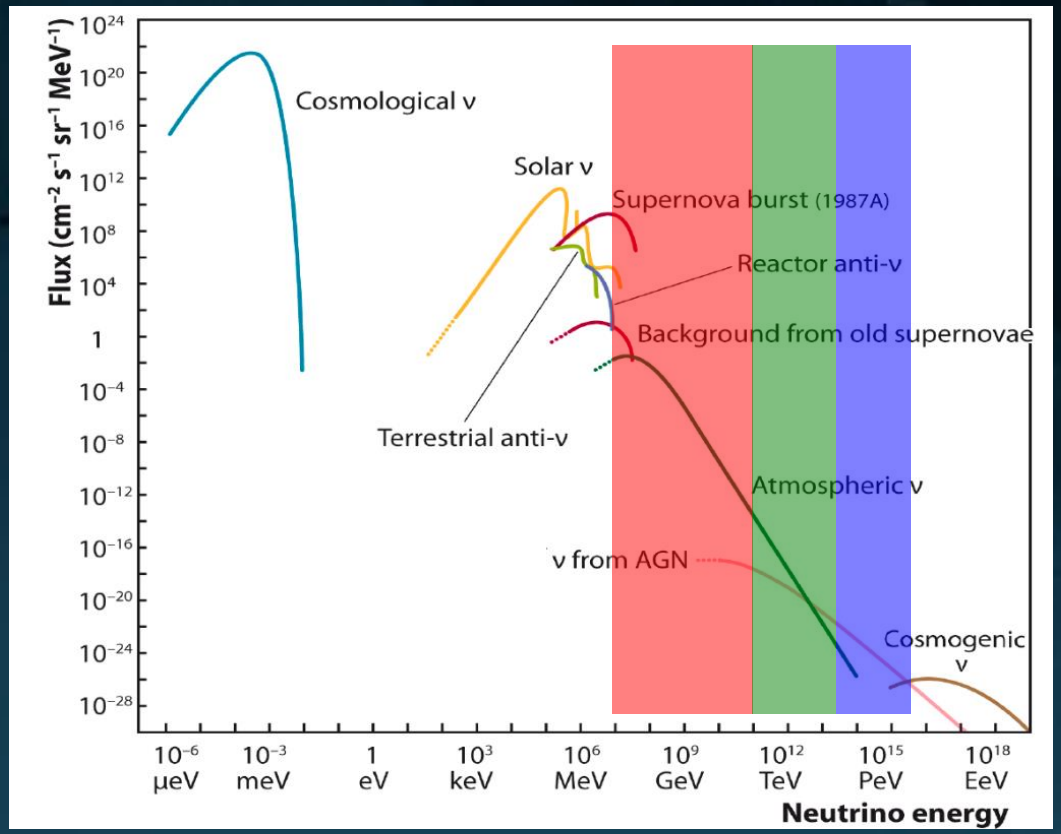
Distortion by Earth matter effects (NMH-dependence): max. diff. NH↔IH for resonance in Earth mantle: θ=130° (7645 km), E_ν=7 GeV



Measure zenith angle and energy of up-going ν_{atm} (~GeV) (identify and count ν_μ and ν_e channel events)

Akhmedov, Razzaque & Smirnov, JHEP 02 (2013) 082

KM3NeT SCIENCE: NEUTRINO SOURCES AND EXPECTED FLUXES



NEUTRINO ENERGIES

~ MeV – 100 GeV
NMH with atmospheric flux

100 GeV - 30 TeV
Several galactic (gamma) sources

30 TeV – 3 PeV
IceCube signal (astrophysical flux)

Other fluxes and energies?

ν_{atm} oscillation experiments ⟷ ν-astronomy (+astrophysics) ← PHYSICS

higher densities ⟷ larger volumes ← DETECTOR REQUIREMENTS

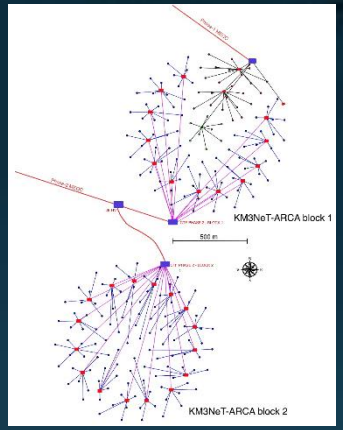
PART 2

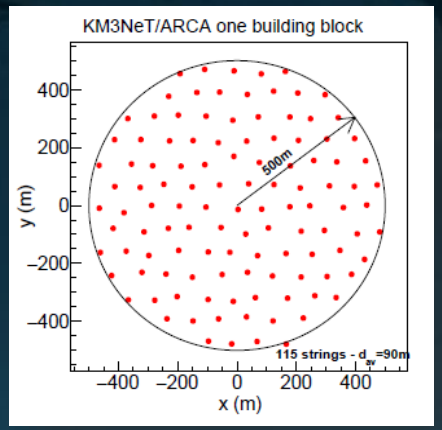
THE KM3NeT NEUTRINO DETECTORS

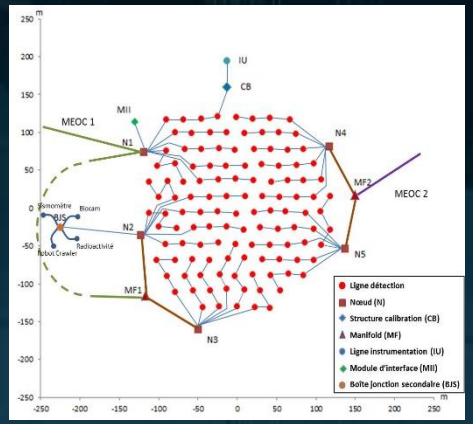
KM3NeT NEUTRINO DETECTORS (PHASE-II)

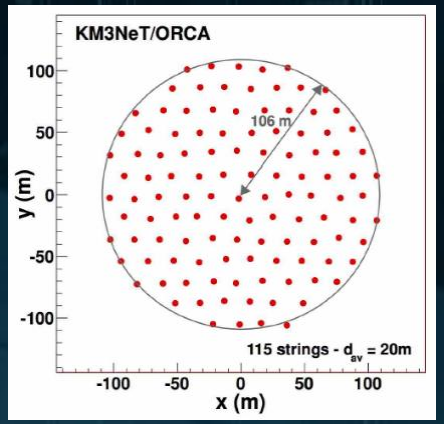
ARCA (Sparser Detector)
Large volume, low fluxes optimization, large effective area
[astrophysical neutrinos]

ORCA (Denser Detector)
High density, low threshold optimization, sensitivity to changes of flavour
[atmospheric neutrinos]









2 Building Blocks (BBs)
[2 x 115 Detection Units (DUs)]
(~ 1 Gton instrumented)

1 Building Block (BB)
[1 x 115 Detection Units (DUs)]
(~ 6 Mton instrumented)

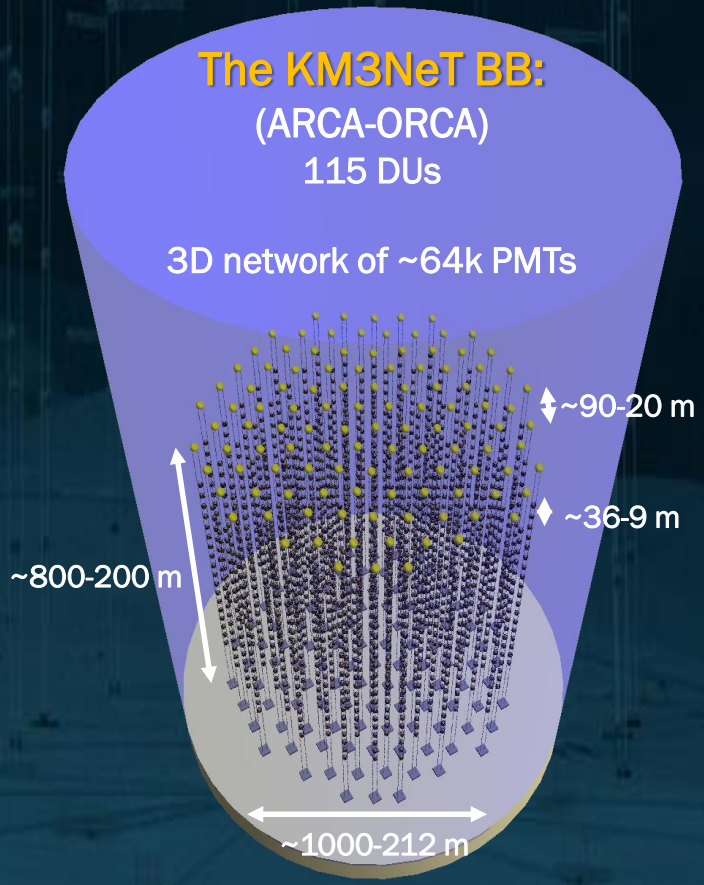
SAME TECHNOLOGY AND LAYOUT (DIMENSIONS SCALED)

KM3NeT SEA CAMPAIGNS

KM3NeT DETECTION UNIT

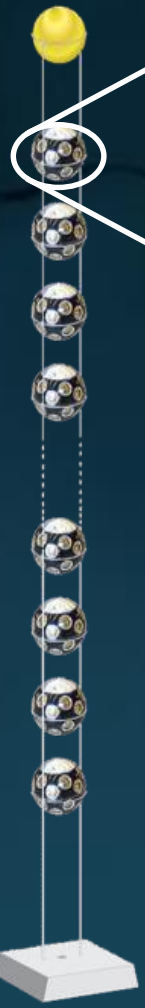
- ✓ 18 DOM on vertical slender strings tied by 2 parallel Dyneema® ropes, 31x3'' PMTs / DOM.
- ✓ White Rabbit (WR) time synchronization protocol.
- ✓ Backbone: 2 copper conductors, 18 fibers (+spares).
- ✓ Break out of cable at each DOM.
- ✓ Optical fiber transmission (Gbit/s) by base module with DWDM at string anchor.
- ✓ All-data-to-shore concept: Filtering/Trigger on-shore in computer farm.

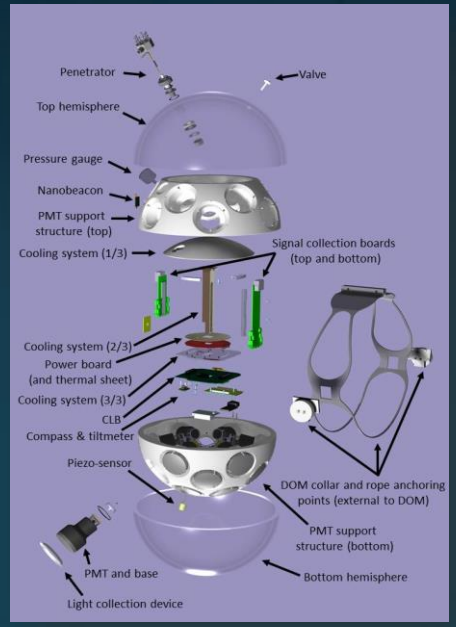
+ Nodes for long-term high-bandwidth connection for Life and Earth Sciences



KM3NeT DIGITAL OPTICAL MODULE

See poster by G.M. Mendoza-Celorio in this event!





DOM Generalities

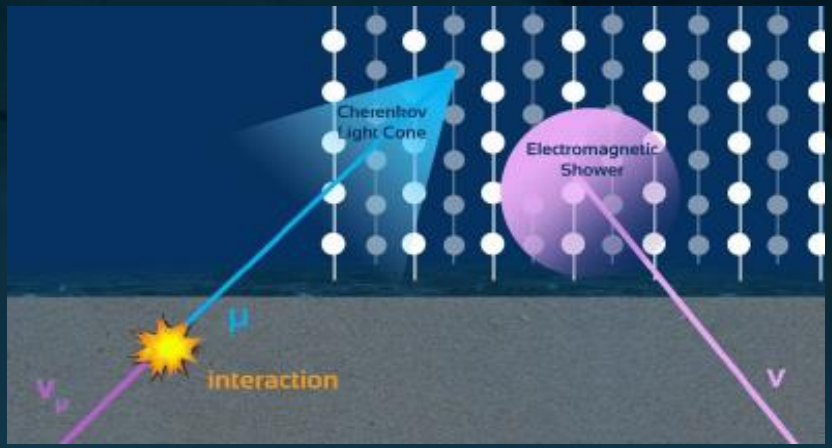
Directional Sensitivity
Segmented cathode area (31x3” PMTs)
+
Improved Photon Counting
Light concentrator ring, cathode area (~3x10’’ PMT)
+
Less overhead, improved readout and calibration devices
Central Logic Board (+Power Board): FPGA readout, compass and tiltmeter inside. NanoBeacon (LED systems), piezo-sensors

PMT Specifics

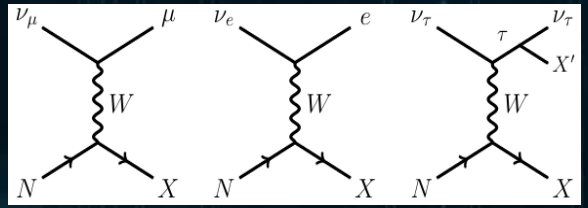
Timing
≤2 ns (RMS)
QE
≥25-30%
Collection efficiency
≥ 90%
Photon counting purity
100%
Price/cm^2
≤10” PMT

NEUTRINO DETECTION IN KM3NeT

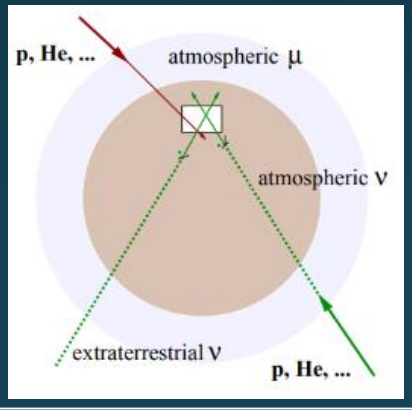
ALL FLAVOUR NEUTRINO OBSERVATION: 6 orders of magnitude in *E(GeV-PeV)*

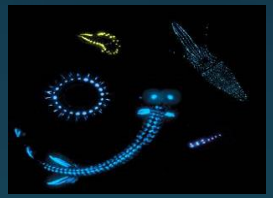


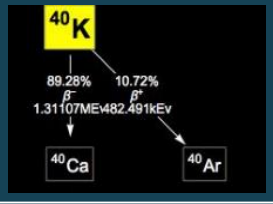
Indirect neutrino detection

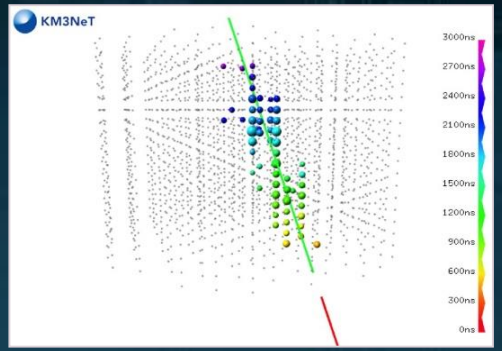


Signal Vs Background

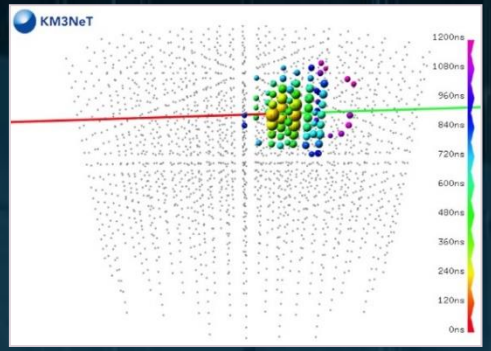








Events far from the detector:
large effective volume



Events inside the detector:
smaller effective volume

Reconstruction of arrival direction and energy of neutrinos:
position + timing + amplitude of the hits

PART 3

KM3NeT FIRST RESULTS (SELECTION)

KM3NeT PERFORMANCE

AN OUTSTANDING DESIGN, A PROPERLY CALIBRATED DETECTOR ...

ARCA GOALS: astrophysical neutrinos ($E_\nu > 10$ *TeV*)

- Track-like events (muons) → α (median) < 0.2°, ΔE ~ 0.3
- Shower-like events → α (median) < 2°, ΔE ~ 0.1

ORCA GOALS: atmospheric neutrinos (*MeV* < E_ν < *GeV*)

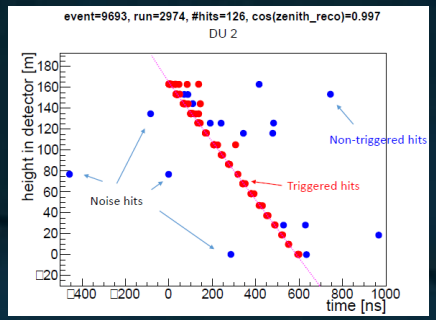
- Angular and energy resolution, and effective area depending on the energy threshold.

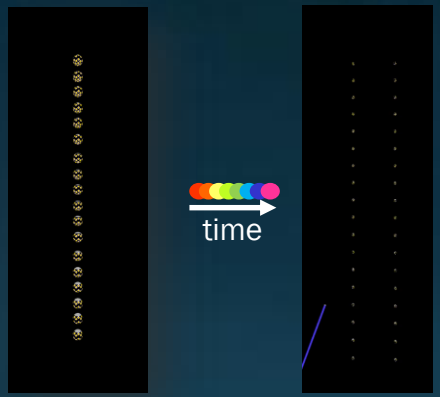
REQUIREMENTS OF THE DETECTOR:

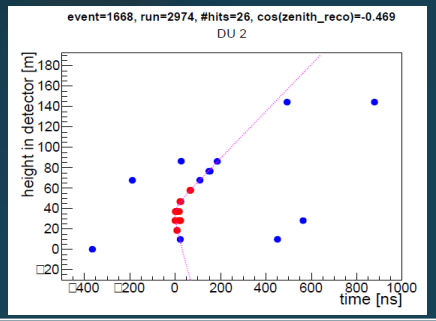
See poster by B.D. Darquea in this event!

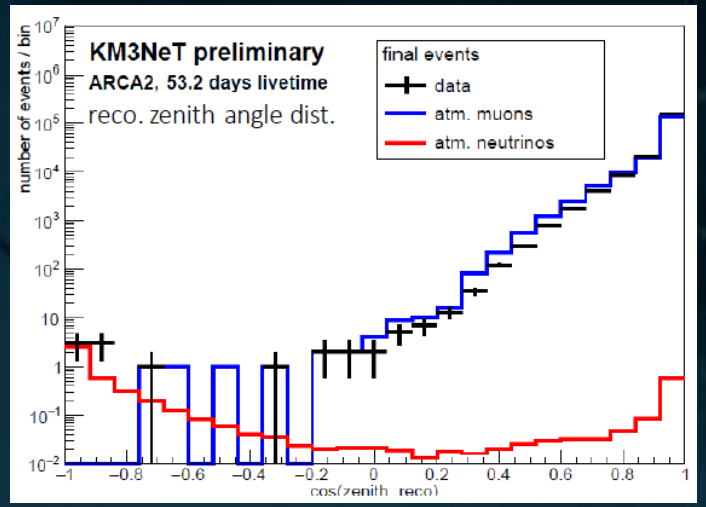
- Timing → Relative hit times accuracy *~ 1 ns*
- Positioning / Orientation → DOM position accuracy *< 20 cm* (distance traveled by Cherenkov photons in *1 ns*) / DOM orientation accuracy *< 3°*
- Optical → Effect of λ_{abs}, λ_{sca}, λ_{tr} , η accounted in the design (OCS TBD)

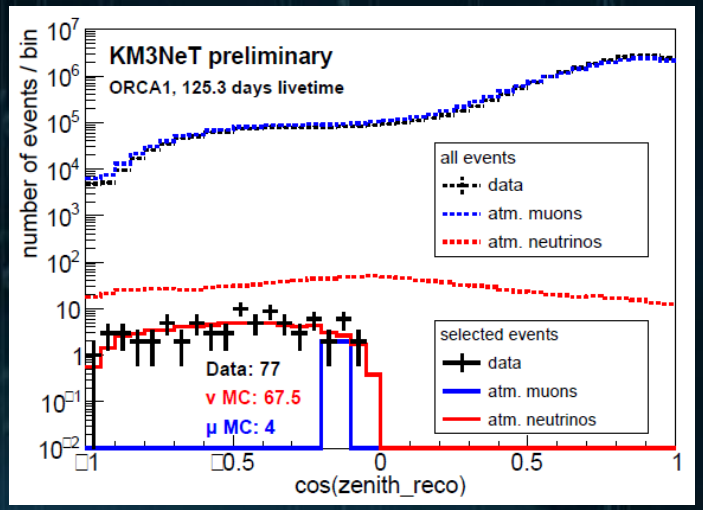
KM3NeT TRACK RECONSTRUCTION











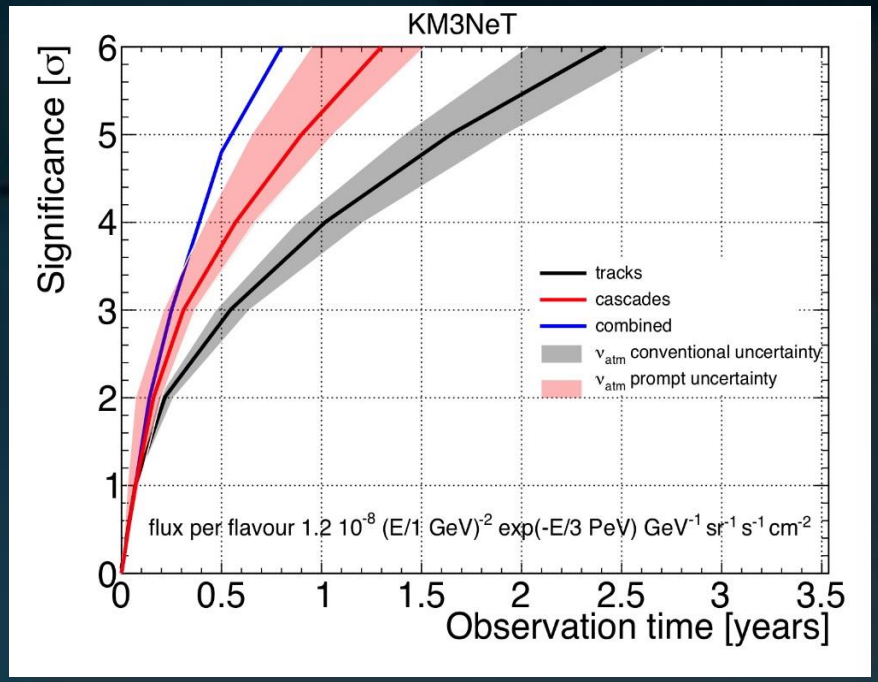
ARCA:
6 up-going neutrino candidates
[*cos(zenith_reco)<-0.8*]

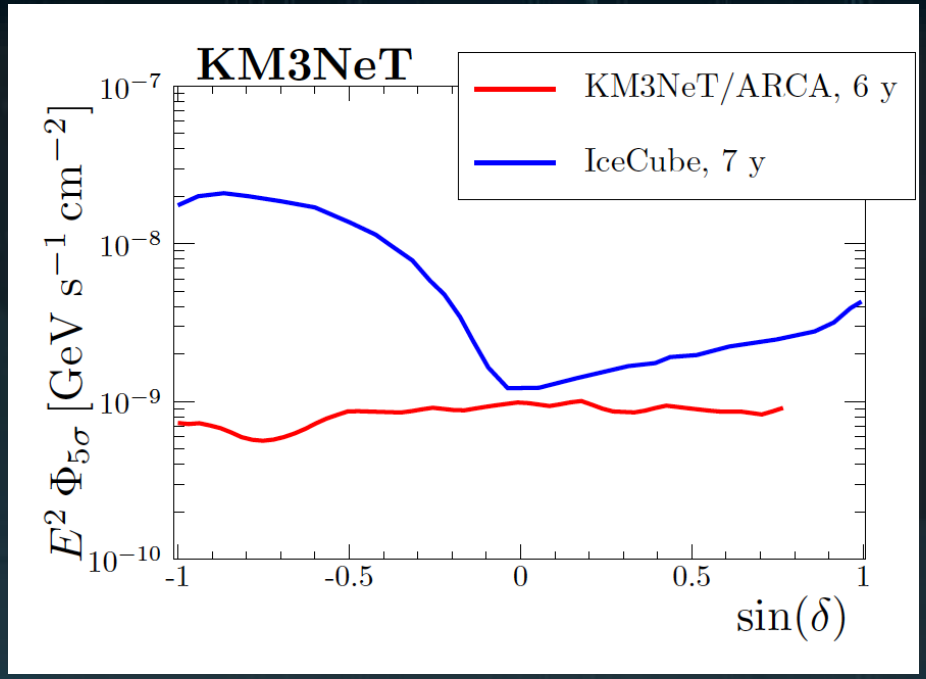
ORCA:
11 up-going neutrino candidates
[*cos(zenith_reco)<-0.8*]

KM3NeT is able to perform an outstanding reconstruction with only a few lines and short lifetime !!!

R. Coniglione. PoS, Volume 358, 36th International Cosmic Ray Conference 2019

KM3NeT SENSITIVITY TO DIFFUSE FLUX (ALL SKY) / POINT-LIKE SOURCES



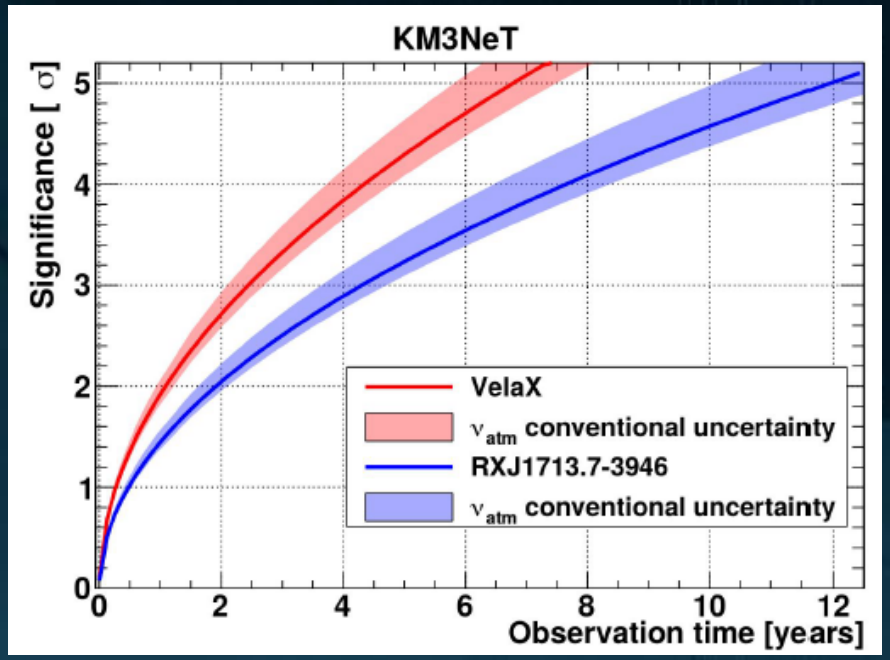


Discovery at 5σ significance in less than one year !!!

Excellent sensitivity (E^{-2}) at southern hemisphere

P. Sapienza, A. Trovato. Astroparticle Physics 111 (2019) 100

KM3NeT SENSITIVITY TO POINT-LIKE SOURCES (E^{-2})



2 Building Blocks (ARCA) (Phase-II)

Good sensitivity thanks to good visibility of galactic plane (sources observed by HESS)

ν-flux from S. R. Kelner, F. A. Aharonian, and V. V. Bugayov, Phys. Rev. D 74, 034018 (2006)

CONCLUSIONS

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1. Operational experience, technical and scientific outcomes of previous Mediterranean Neutrino Telescopes have been fundamental for KM3NeT.

2. Mass production phase has started, integration and deployment of DUs will be pursued at a continuous pace, at the highest priority level.

3. Discovery of astrophysical neutrino sources at 5σ significance in less than one year. Excellent sensitivity at southern hemisphere and field of view to Galactic sources.

4. Outstanding results in all science programs for a very short KM3NeT life-time.

5. Lots of opportunities are being open for Ecuador and Latinamerica through future KM3NeT collaborators.

THANKS SO MUCH AND STAY TUNED!

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LASF4RI National Representative (https://lasf4ri.org/)