

# The KM3NeT project ARCA + ORCA

E.T. de Boone

April 21st, 2020

## └ Outline

## Outline

- General Info
  - KM3NeT
- Detector Design
- ORCA - Particle Physics
- ARCA - Astroparticle Physics

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- 1 General Info
  - KM3NeT
- 2 Detector Design
- 3 ORCA - Particle Physics
- 4 ARCA - Astroparticle Physics

The prototype detection unit of the KM3NeT detector  
KM3NeT Collaboration

PAPER • OPEN ACCESS

Letter of intent for KM3NeT 2.0

To cite this article: S Adrián-Martínez et al 2016 *J. Phys. G: Nucl. Part. Phys.* **43** 084001

## The prototype detection unit of the KM3NeT detector

KM3NeT Collaboration

PAPER • OPEN ACCESS

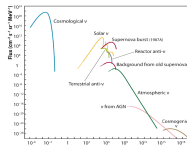
## Letter of intent for KM3NeT 2.0

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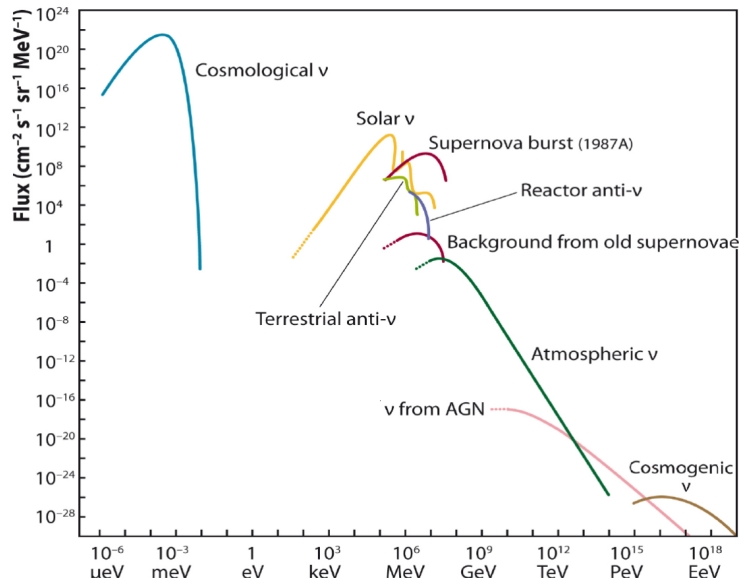
## └ Astrophysical vs Atmospheric Neutrino

- Distinction Atmospheric vs Astrophysical
  - steep decline for  $\gtrsim$  TeV
  - lower energies
- Observatories: IceCube, ANTARES
  - IceCube: 100 GeV - several PeV
  - ANTARES: 10 GeV - 100 TeV
- Types of events
  - Tracklike (through-going)
  - Showerlike

Astrophysical vs Atmospheric Neutrino



## Astrophysical vs Atmospheric Neutrino



- Deep-sea neutrino telescope
- Three locations in the Mediterranean Sea

# KM3NeT

1. Observation Principle IceCube
2. Locations: Toulon (FR), Sicily (It), Pylos (Gr)
3. Properties Water

## Cubic Kilometer Neutrino Telescope

- Deep-sea neutrino telescope
- Three locations in the Mediterranean Sea

## Cubic Kilometer Neutrino Telescope

- Deep-sea neutrino telescope
- Three locations in the Mediterranean Sea
- 2 Main objectives
  - Determine the Neutrino Mass Hierarchy
  - Observe the Universe with highly energetic Neutrino's

## KM3NeT

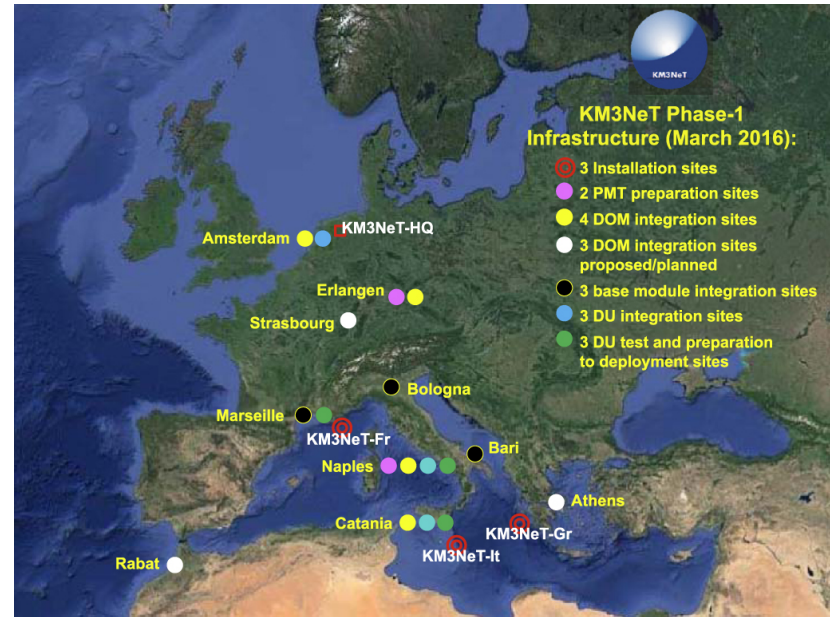
- Neutrino Mass Hierarchy
  - Neutrino's have mass
  - flavour eigenstates *neq* mass eigenstates
- Universe
  - Objectives to confirm icecube findings
  - Counterpart to IceCube - Galactic Plane in FoV

## Cubic Kilometer Neutrino Telescope

- Deep-sea neutrino telescope
- Three locations in the Mediterranean Sea
- 2 Main objectives
  - Determine the Neutrino Mass Hierarchy
  - Observe the Universe with highly energetic Neutrino's



- Spread over large part of mediterranean sea
- Reason for locations: deep water
- Successor to and experience from:
  - ANTARES (Fr)
  - NEMO (It) - Pilot
  - NESTOR (Gr) - Pilot
- Greece is pending future funding



# KM3NeT

- 2 main objectives
  - Determine the Neutrino Mass Hierarchy
  - Observe the Universe using Neutrino's

- 2 main objectives
  - Determine the Neutrino Mass Hierarchy
  - Observe the Universe using Neutrino's



- ORCA in Fr, ARCA in Italy
- Combined sensitivity from GeV to above PeV: 6 orders of magnitude
- ORCA:
  - Focus on atmospheric neutrinos
  - densely packed  $\mapsto$  GeV to TeV  $\nu$ 's
- ARCA:
  - Focus on (extra)galactic neutrinos
  - sparsely packed  $\mapsto$  TeV to PeV  $\nu$ 's
- shared technology

- 2 main objectives
  - Determine the Neutrino Mass Hierarchy
  - Observe the Universe using Neutrino's
- 2 main experiments
  - ORCA: Oscillation Research with Cosmics in the Abyss
  - ARCA: Astroparticle Research with Cosmics in the Abyss

## ■ 2 main objectives

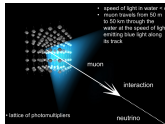
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- Observe the Universe using Neutrino's

## ■ 2 main experiments

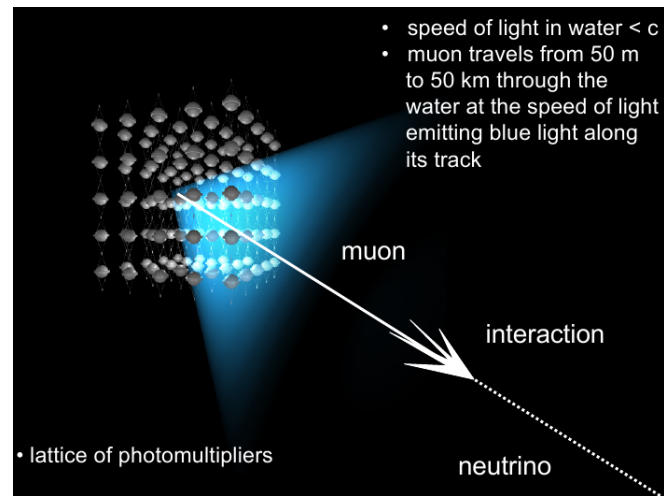
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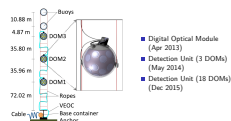


- Old design =  $\surd$  Markov 1960 multiple predecessors
- compare with IceCube, ANTARES, DUMAND
- Cherenkov light
- Digital-Optical Module

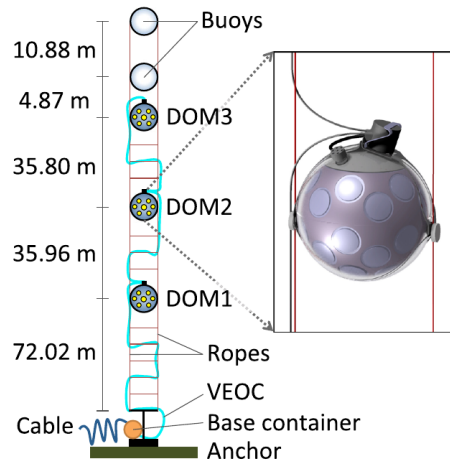


## Detector Design

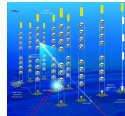




# Detector Prototypes

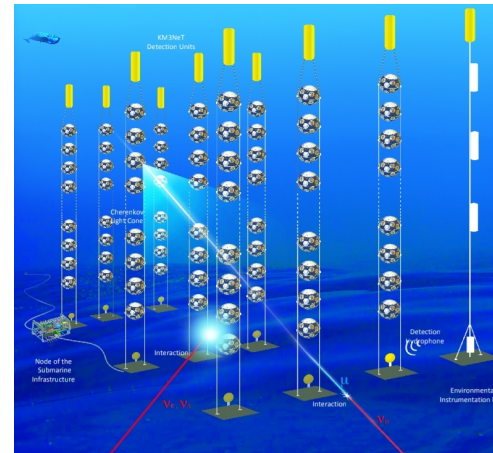


- Digital Optical Module (Apr 2013)
- Detection Unit (3 DOMs) (May 2014)
- Detection Unit (18 DOMs) (Dec 2015)



Building Block

- 115 strings
- 18 Digital Optical Modules per string
- 31 Photo Multiplier Tubes per DOM



- lattice structure (also on prev slides)
- data transmission fibre-optics (1 Gbps per DOM)
- $31 \times 18 = 558$  PMTs per string
- $558 \times 115 = 64170$  PMTs per block

### Building Block

- 115 strings
- 18 Digital Optical Modules per string
- 31 Photo Multiplier Tubes per DOM

- PMT: gain  $10^6$
- PMT: compare amount with IceCube: 1:31
- Acoustics: resolution to 20 cm  $\mapsto$  1 ns

## Sensors

- 31 PMTs per DOM  
 $\mapsto$  1400cm<sup>2</sup>
- Acoustic Sensor
- Compass
- Accelerometers



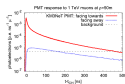
## Digital Optical Modules

## Sensors

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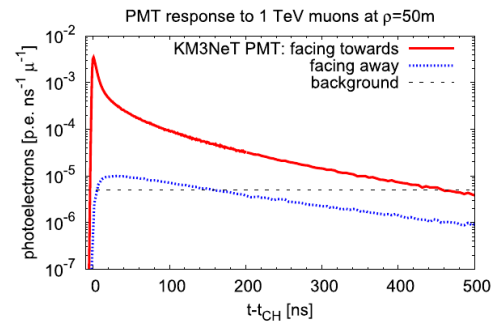
- Data each 8ns
- Start Time (0.3 photo-electrons)
- Time over Threshold
- "All Data to Shore"
- $2^{24} \times 8\text{ns} \approx 134\text{ms}$



## DOM Data

- DOM uplink 1Gbps

- Data each 8ns
  - Start Time (0.3 photo-electrons)
  - Time over Threshold
- "All Data to Shore"
- $2^{24} \times 8\text{ns} \approx 134\text{ms}$



- 8ns data
- $1\text{ns} \times c = 30\text{cm} \mapsto \Delta x \approx 2.40\text{m}$

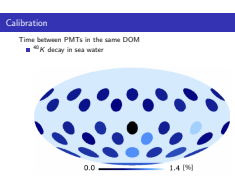
- Nanosecond level precision
  - Time between PMTs in the same DOM
  - Time between DOMs

# Calibration

- Nanosecond level precision
  - Time between PMTs in the same DOM
  - Time between DOMs



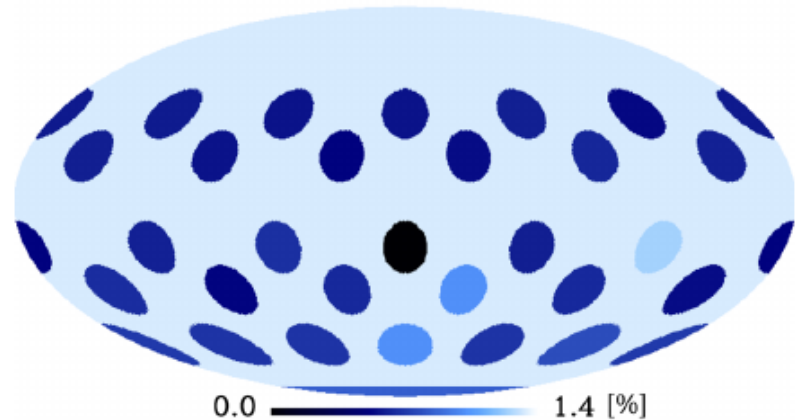
- $^{40}\text{K}$  decay
  - $\lambda_{1/2}$  Gyr
  - 150 Cherenkov  $\gamma$  per decay



## Calibration

Time between PMTs in the same DOM

- $^{40}\text{K}$  decay in sea water



- LED: 470nm, fully controlled from shore ( $I, f$ )
- comparison of timings on the same string
- Acoustics: position calibration

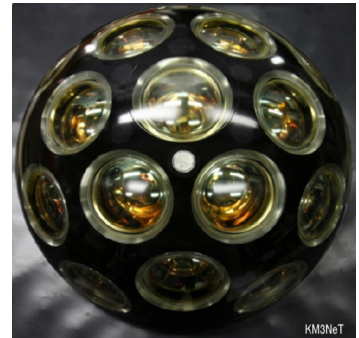


# Calibration



## Time between DOM

- LED nanobeacon
- Acoustic Piezo sensor



- $^{40}\text{K}$  decay in seawater
- Bioluminescence
- Dust in water

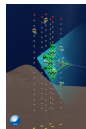
# Background Effects

- $^{40}\text{K}$  is background but also calibrator
- bioluminescence: marine sciences, effect of upto 10%
- 

- $^{40}\text{K}$  decay in seawater
- Bioluminescence
- Dust in water

## Multiple Triggers

- L0: 0.3 photo-electrons in PMT (in DOM)
- L1: 2 hits in separate PMTs within 25ns
- L2: use orientation of PMTs

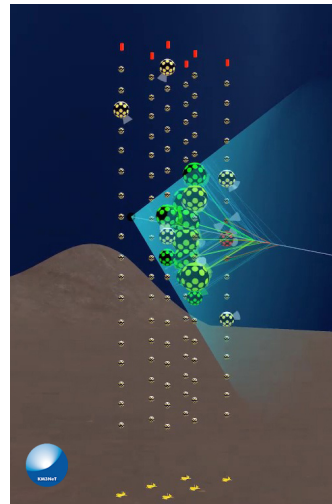


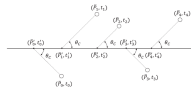
## Event Triggers

- L1:
  - 1kHz per DOM of which 0.6 is  $^{40}K$  decay.
  - study gives relative time offset mostly 10 ns.
- L2: halves the remaining hits
- Causality: 25ns  $\mapsto$  7.5m

## Multiple Triggers

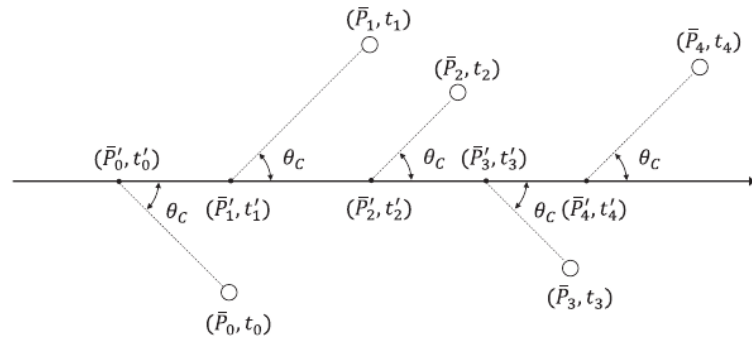
- L0: 0.3 photo-electrons in PMT (in DOM)
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## Event Triggers: Muon Tracks and Showers

- Various Trigger Algorithms
- Muon track
- directional filter  $\sim 10^\circ \mapsto 200$  directions cover  $4\pi$
- shower events



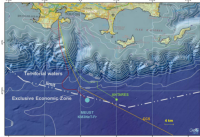
2020-04-20

The KM3NeT project ARCA + ORCA

└ ORCA - Particle Physics

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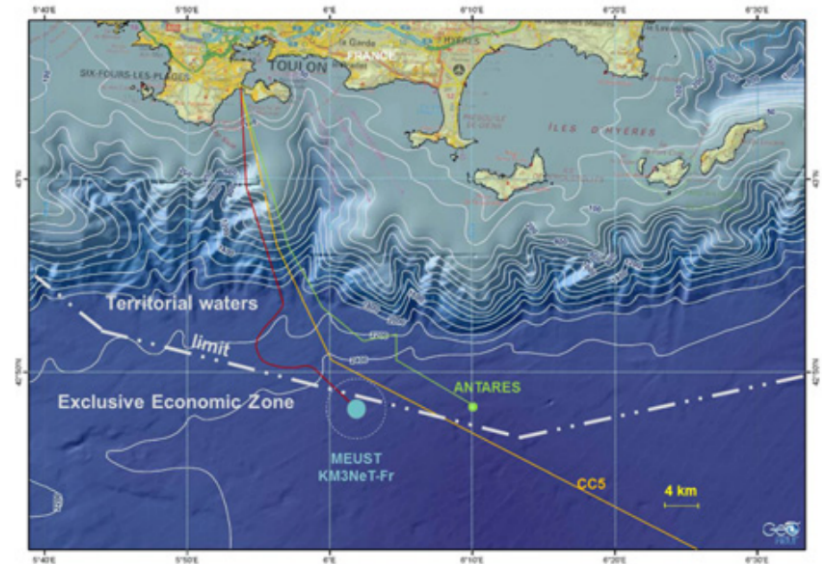
ORCA - Particle Physics



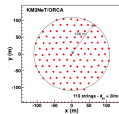
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└ ORCA - Particle Physics

## ORCA - Particle Physics



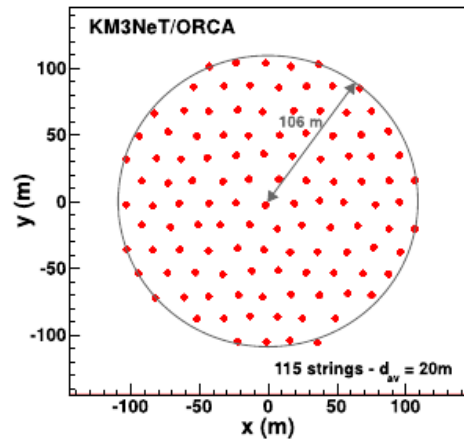
- 1 Building Block
- dense packing  $\rightarrow$  sensitivity GeV to TeV

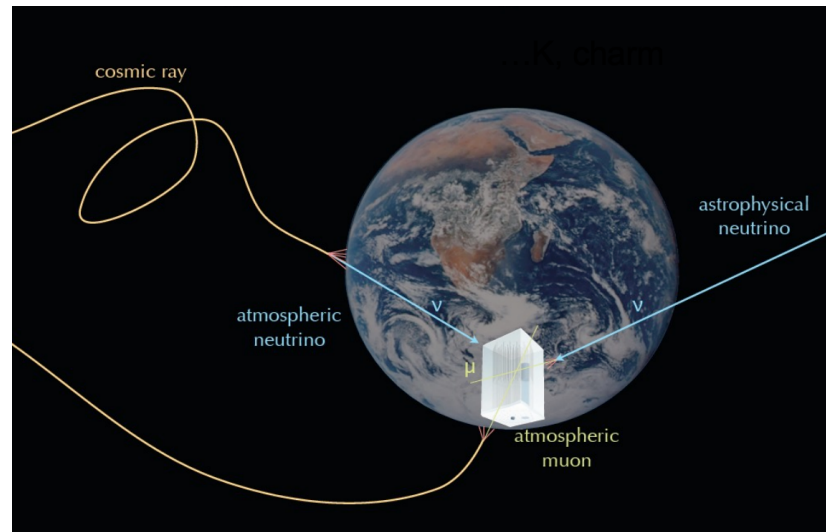
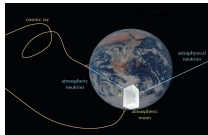


## ORCA - Particle Physics

- depth: 2500m
- height: 150m
- width: *see frame*
- instrumented volume: 8 Million tonnes of water
- horizontal distance 20m
- vertical distance 6m

- 1 Building Block
- dense packing  $\rightarrow$  sensitivity GeV to TeV

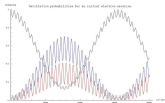






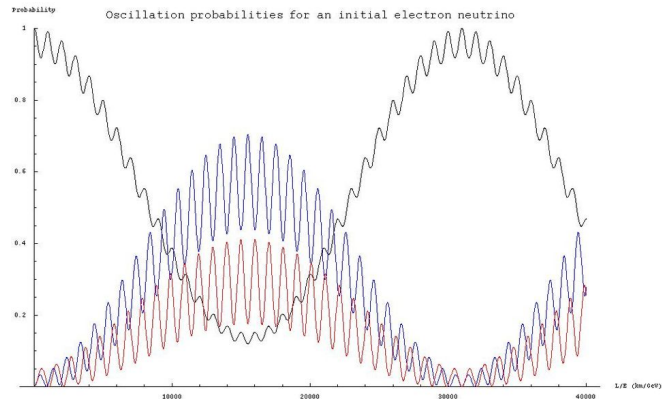
- solar neutrino puzzle
- 
- mass eigenstates  $\neq$  flavour eigenstates, mass squared diff

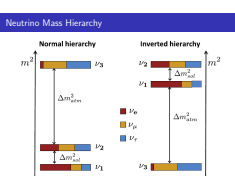
- Pontecorvo - Maki - Nakagawa - Sakata matrix
- 3 angles, 1 phase



## Neutrino Oscillations

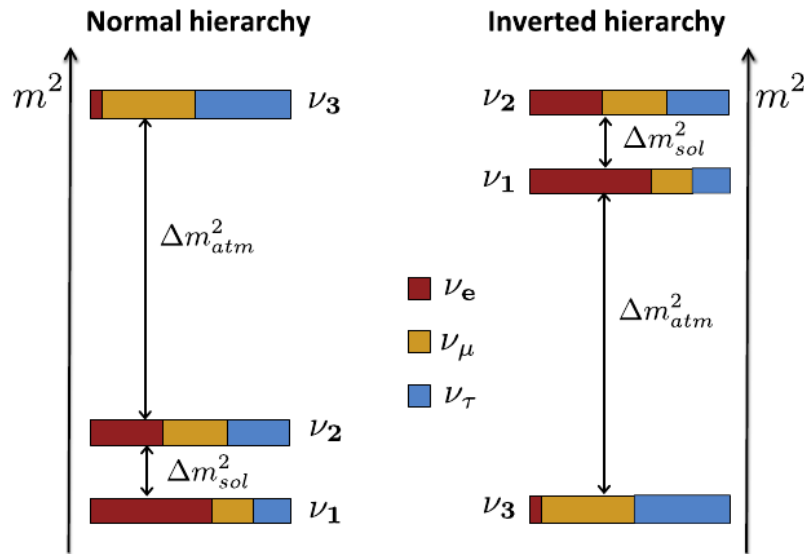
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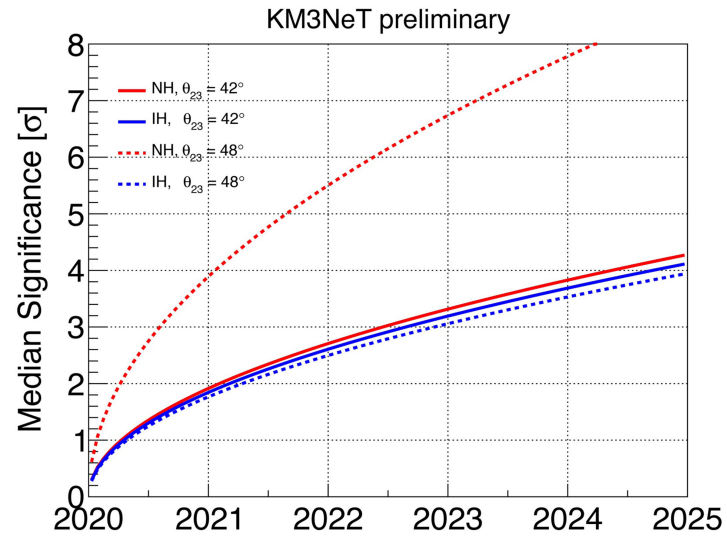
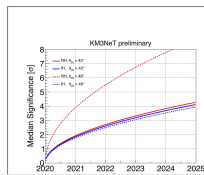




# Neutrino Mass Hierarchy

- vacuum oscillations insensitive to sign of mass sq. diff.
- matter is sensitive  $\mapsto$  different cross-sections for  $\nu$  and  $\bar{\nu}$
- effect largest for  $E_\nu \approx 30 \text{ GeV}/\rho \mapsto 1 - 20 \text{ GeV}$  in KM3NeT
- cannot measure charge
- $\sigma(\nu N) \approx 2\sigma(\bar{\nu} N)$





## The KM3NeT project ARCA + ORCA

└ ARCA - Astroparticle Physics

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ARCA - Astroparticle Physics

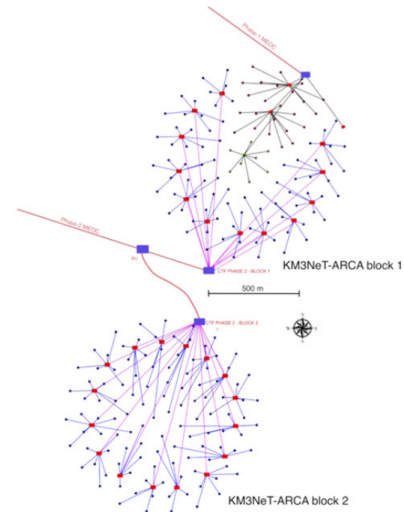


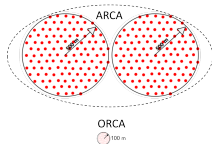
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└ ARCA - Astroparticle Physics

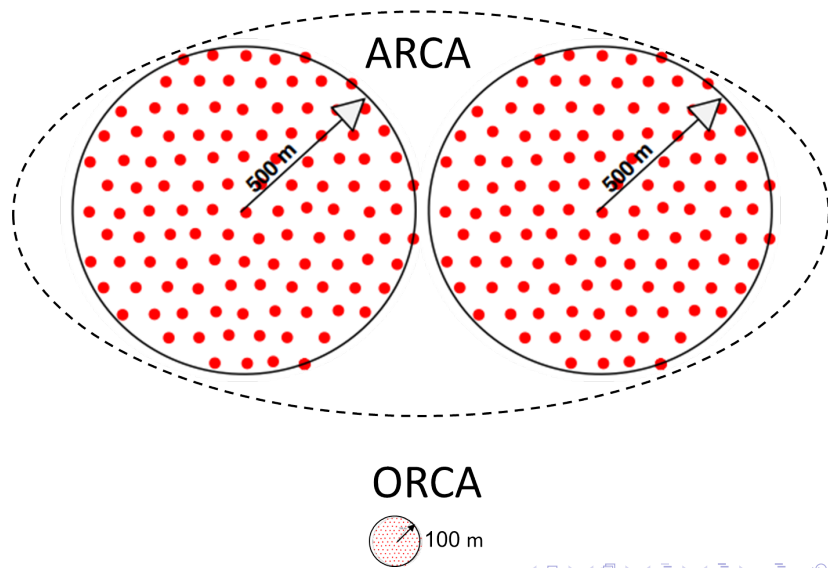
## ARCA - Astroparticle Physics

- horizontal distance 90m
- vertical distance 36m
- depth 3.5km





## Differences between ARCA and ORCA

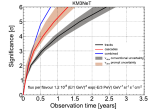


- Signals from 10 TeV to above 1 PeV
- 54 events with reconstructed energy above 30TeV (2016, IceCube)

## IceCube and Expected Signal

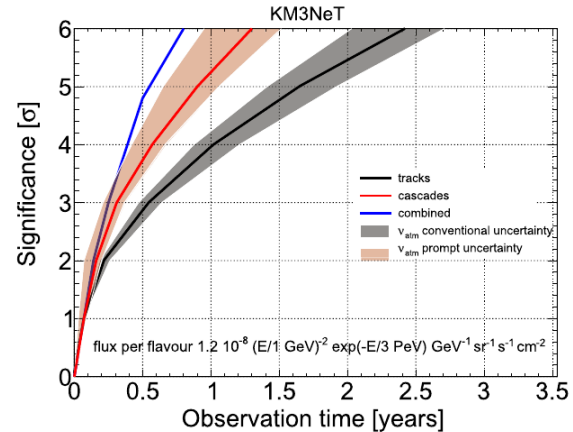
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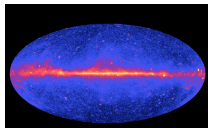


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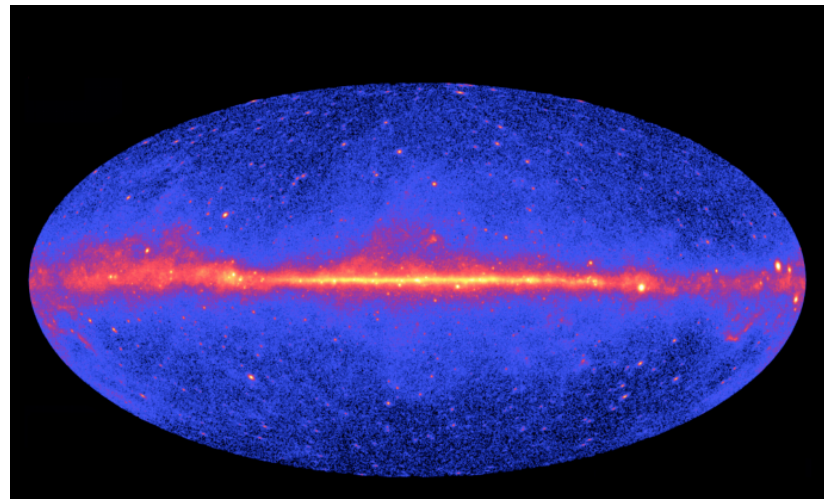
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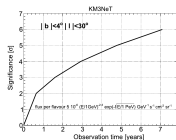
- TeV  $\gamma$ -ray emission from GP
- same hadronic processes lead to high-energy  $\nu$ 's



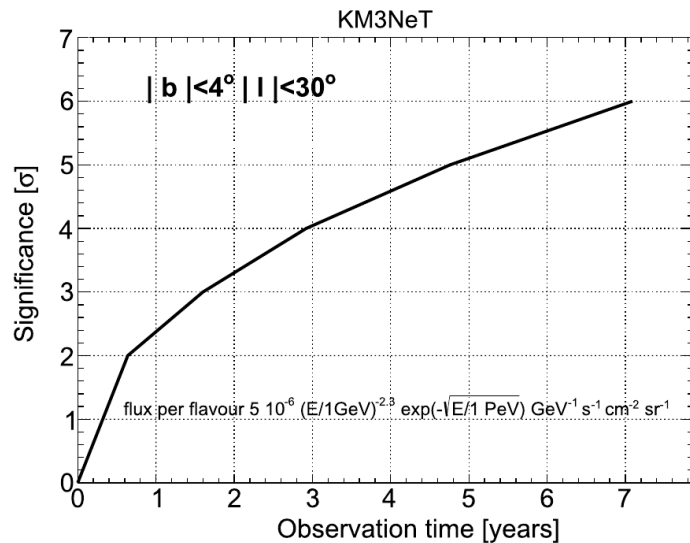
## Expected Signals: Diffuse Flux from Galactic Plane







## Expected Signals: Diffuse Flux from Galactic Plane



- Good Angular Resolution
- Galactic Sources can be probed

## Expected Signals: Point like sources

- Good Angular Resolution
- Galactic Sources can be probed

- Deep-sea Cubic Kilometer Neutrino Telescope in the Mediterranean Sea
- 2 objectives  $\mapsto$  2 experiments
  - ARCA: Astrophysics Research with Cosmics in the Abyss
  - ORCA: Oscillation Research with Cosmics in the Abyss
- Significant results expected within a few years of observations

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Question Time

- Deep-sea Cubic Kilometer Neutrino Telescope in the Mediterranean Sea
- 2 objectives  $\mapsto$  2 experiments
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Question Time



[https://www.youtube.com/watch?v=7HKHW0hLxt4&list=PLL90R\\_-tW5q0tfZigqVpzMmTSwkMjCT1s&index=8](https://www.youtube.com/watch?v=7HKHW0hLxt4&list=PLL90R_-tW5q0tfZigqVpzMmTSwkMjCT1s&index=8)

## Deployment of Strings

[https://www.youtube.com/watch?v=7HKHW0hLxt4&list=PLL90R\\_-tW5q0tfZigqVpzMmTSwkMjCT1s&index=8](https://www.youtube.com/watch?v=7HKHW0hLxt4&list=PLL90R_-tW5q0tfZigqVpzMmTSwkMjCT1s&index=8)