The KM3NeT project ARCA + ORCA

E.T. de Boone

April 21st, 2020

Outline

1 General Info
- KM3NeT

2 Detector Design

3 ORCA - Particle Physics

4 ARCA - Astroparticle Physics

Papers

The prototype detection unit of the KM3NeT detector

KM3NeT Collaboration

PAPER • **OPEN ACCESS**

Letter of intent for KM3NeT 2.0

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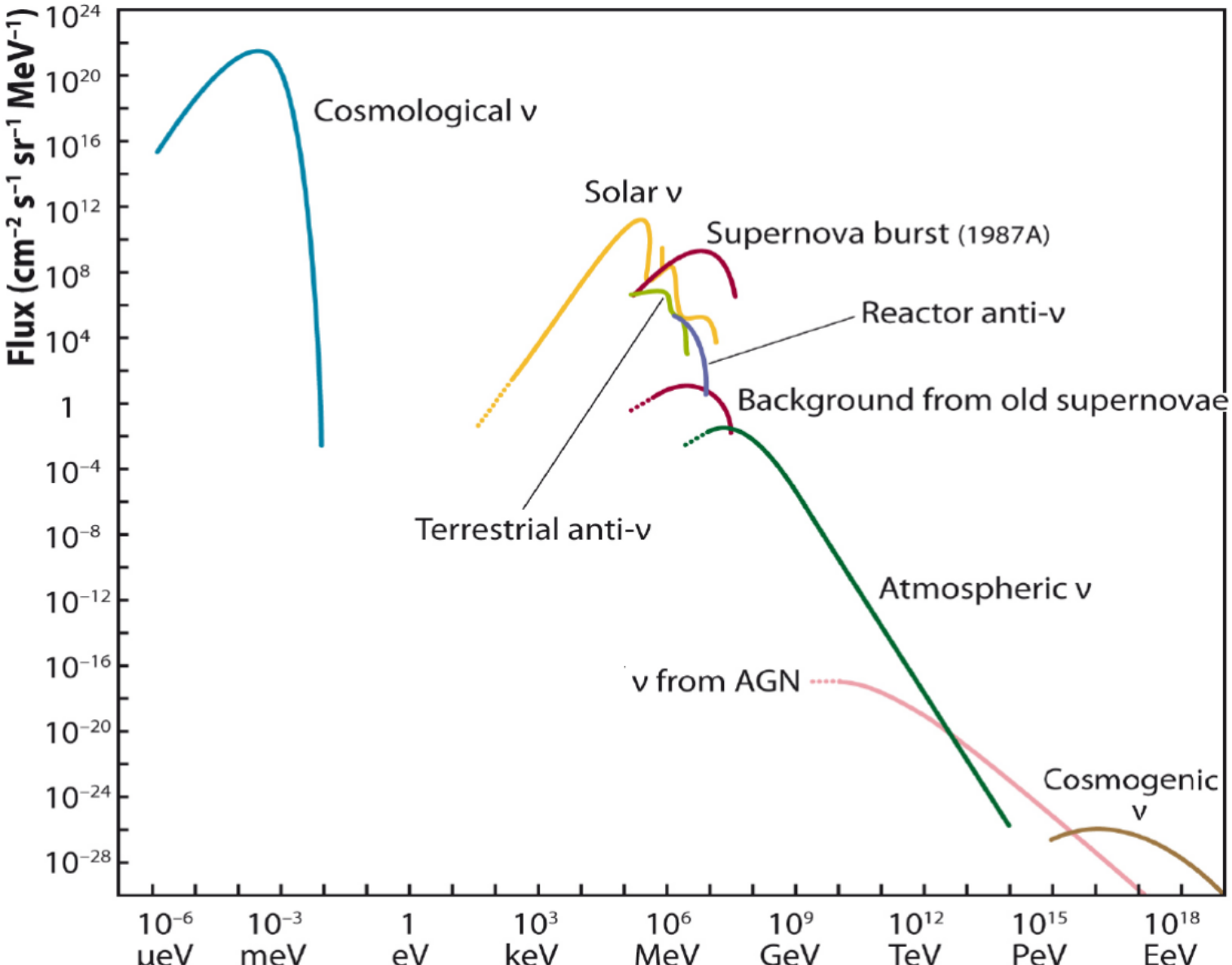
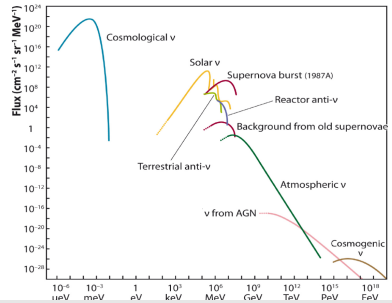
Astrophysical vs Atmospheric Neutrino



The KM3NeT project ARCA + ORCA

Astrophysical vs Atmospheric Neutrino

Astrophysical vs Atmospheric Neutrino



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

KM3NeT

Cubic Kilometer Neutrino Telescope

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

Cubic Kilometer Neutrino Telescope

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- Three locations in the Mediterranean Sea

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

KM3NeT

Cubic Kilometer Neutrino Telescope

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- 2 Main objectives
  - Determine the Neutrino Mass Hierarchy
  - Observe the Universe with highly energetic Neutrino's

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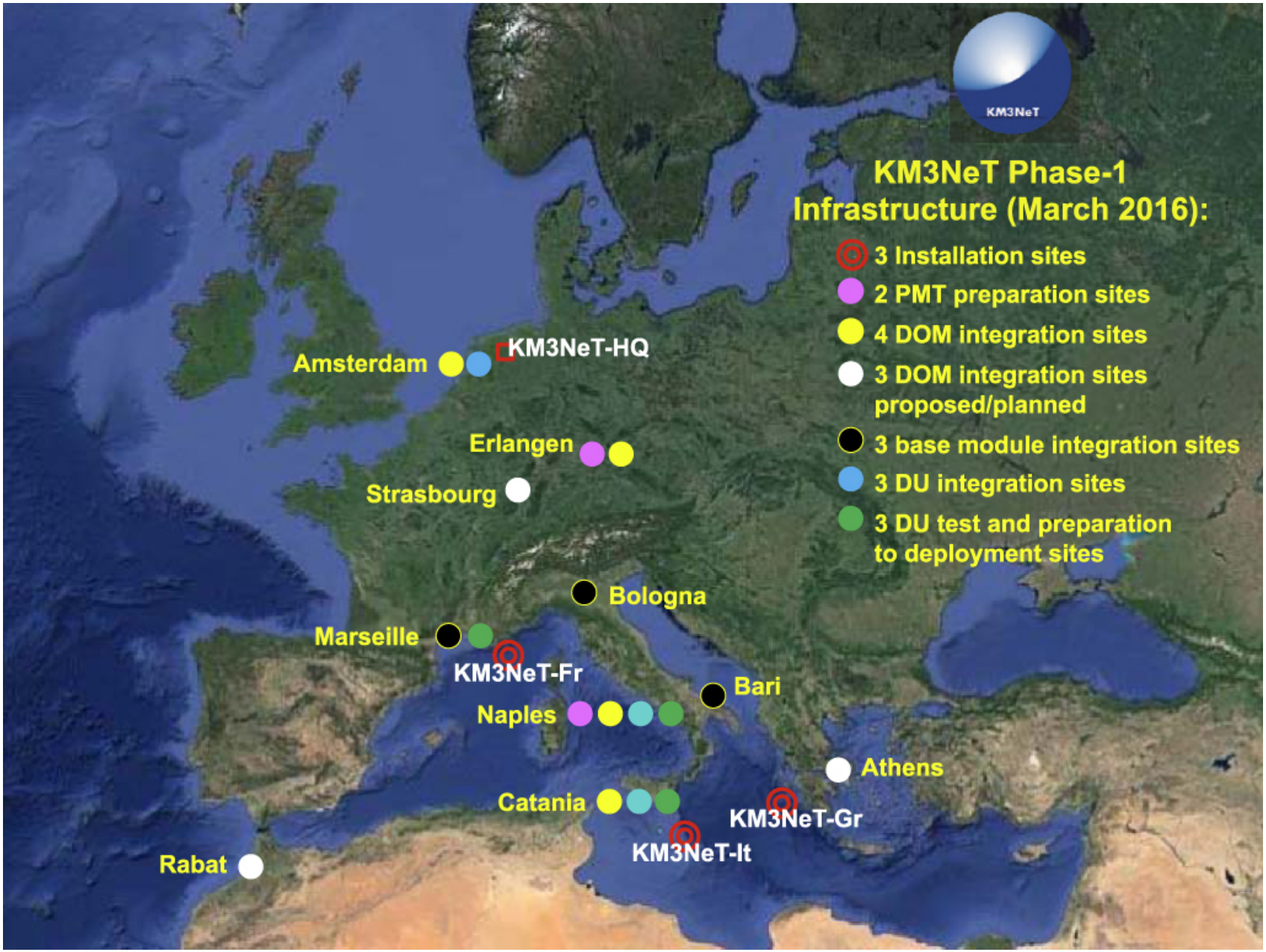
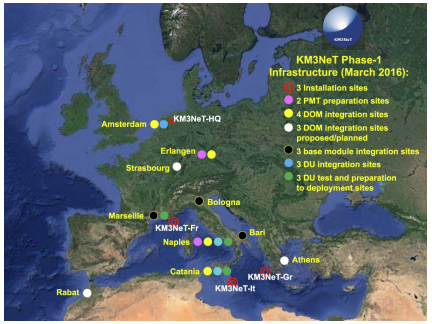
- Neutrino Mass Hierarchy
  - Neutrino's have mass
  - flavour eigenstates *neq* mass eigenstates
- Universe
  - Objectives to confirm icecube findings
  - Counterpart to IceCube - Galactic Plane in FoV


KM3NeT
KM3NeT Phase-1 Infrastructure (March 2016):
3 Installation sites
2 PMT preparation sites
4 DOM integration sites
3 DOM integration sites proposed/planned
3 base module integration sites
3 DU integration sites
3 DU test and preparation to deployment sites
Amsterdam
KM3NeT-HQ
Erlangen
Strasbourg
Bologna
Marseille
KM3NeT-Fr
Bari
Naples
Athens
Catania
KM3NeT-Gr
KM3NeT-It
Rabat



- Spread over large part of mediterranean sea
- Reason for locations: deep water
- Succesor 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
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- 2 main experiments
  - ORCA: Oscillation Research with Cosmics in the Abyss
  - ARCA: Astroparticle Research with Cosmics in the Abyss

KM3NeT

- 2 main objectives
  - Determine the Neutrino Mass Hierarchy
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- 2 main experiments
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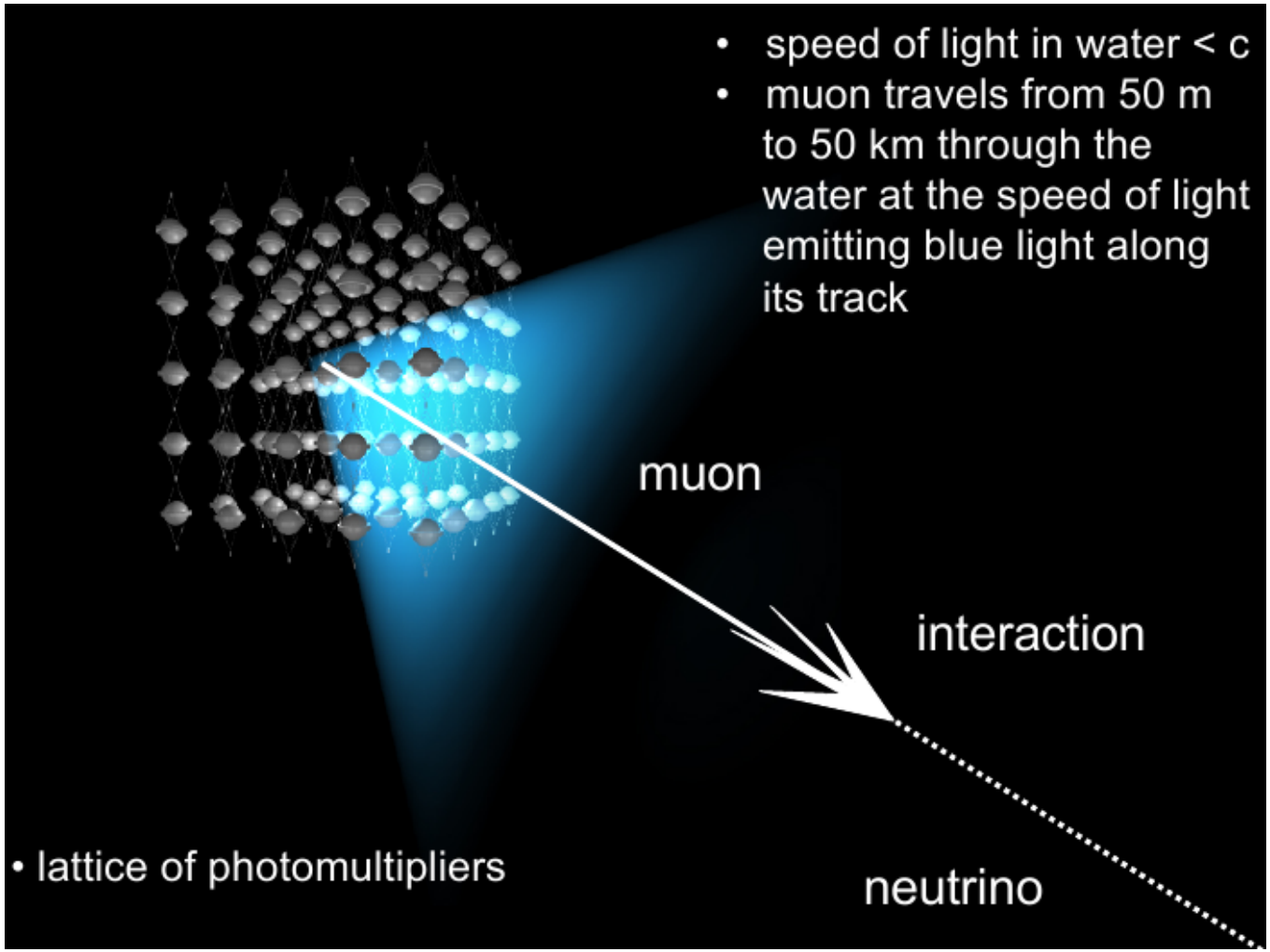
  - ARCA: Astroparticle Research with Cosmics in the Abyss

- 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 ν's
- ARCA:
  - Focus on (extra)galactic neutrinos
  - sparsely packed $\mapsto$ TeV to PeV ν's
- shared technology

Detector Design

Detector Design



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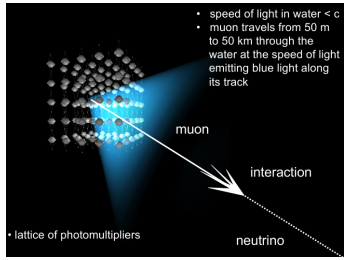
Detector Design

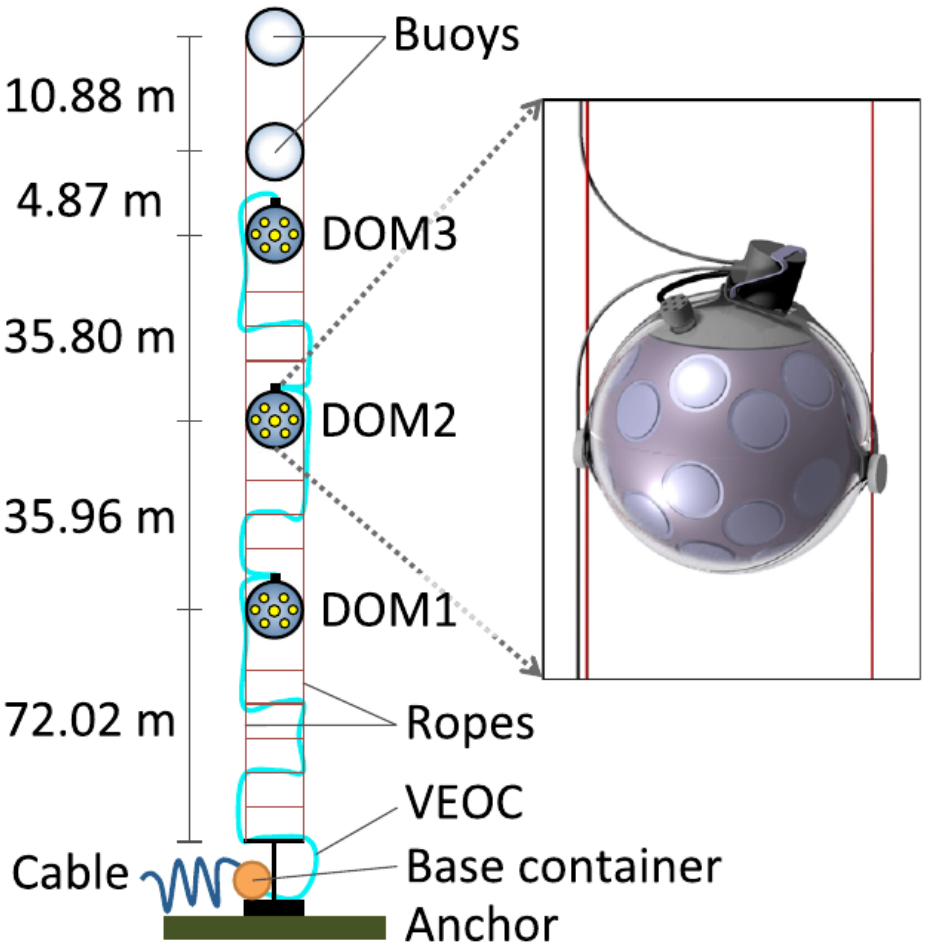
Detector Design



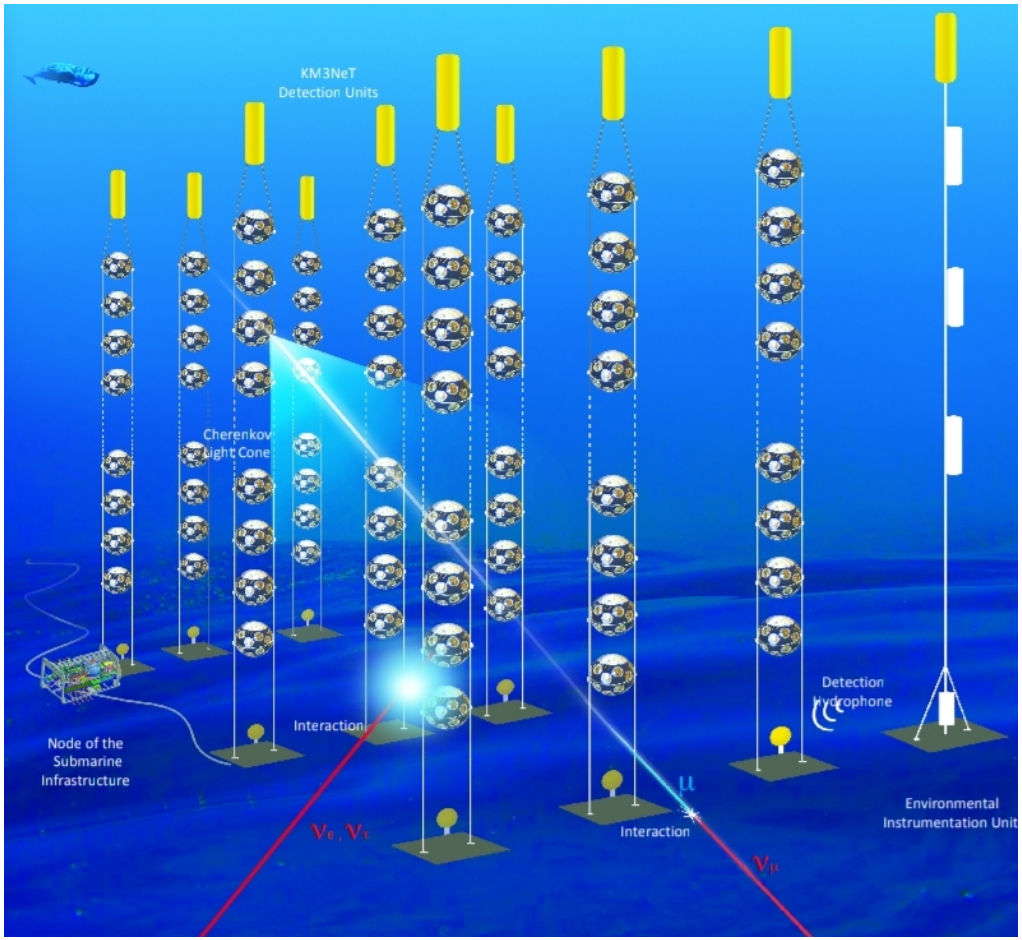
- Old design =¿ Markov 1960 multiple predecessors
- compare with IceCube, ANTARES, DUMAND

- Cherenkov light
- Digital-Optical Module

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

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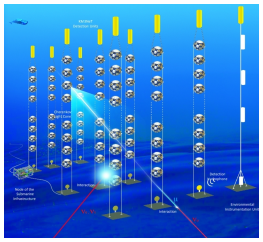


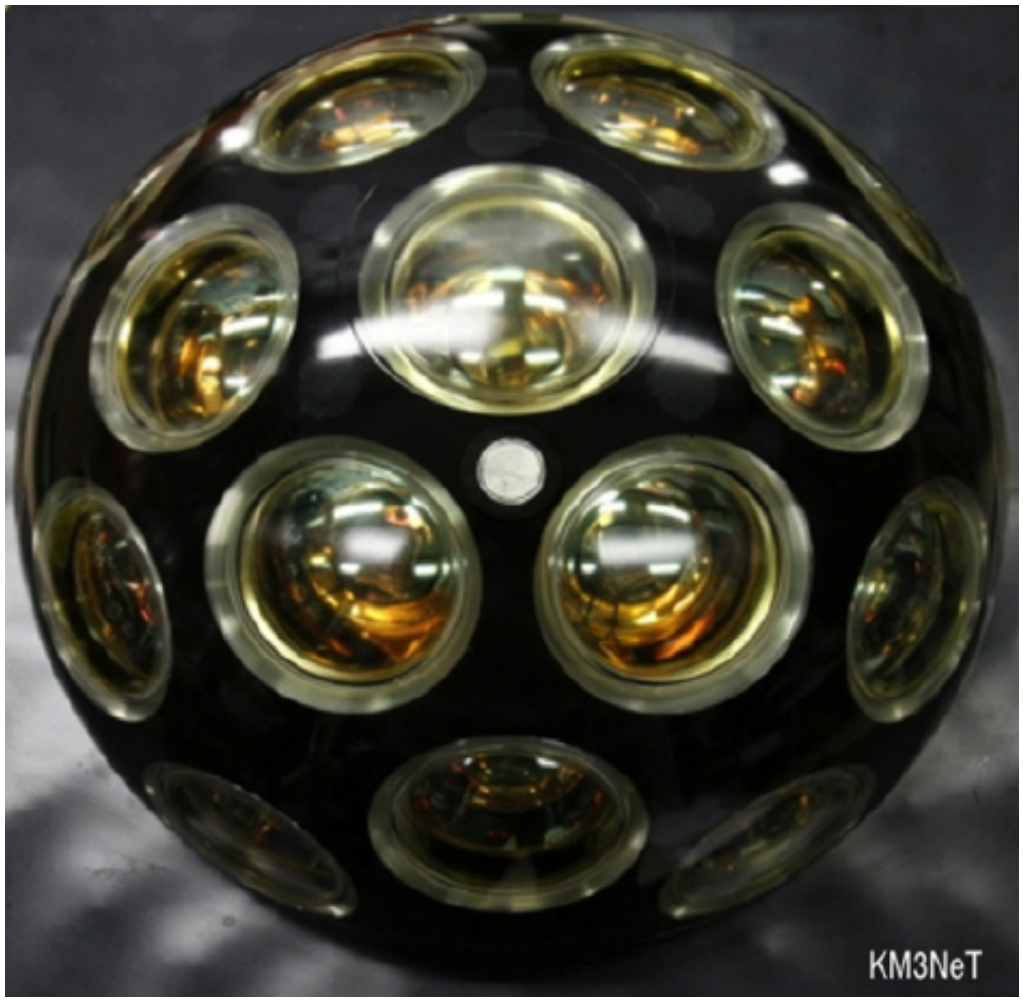
Building Block
- 115 strings
- 18 Digital Optical Modules per string
- 31 Photo Multiplier Tubes per DOM

- 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

Digital Optical Modules

Sensors

- 31 PMTs per DOM
  $\mapsto 1400\mathrm{cm}^2$
- Acoustic Sensor
- Compass
- Accelerometers



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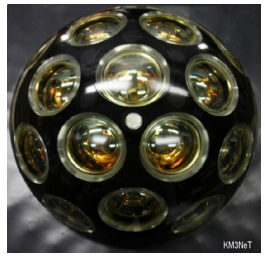
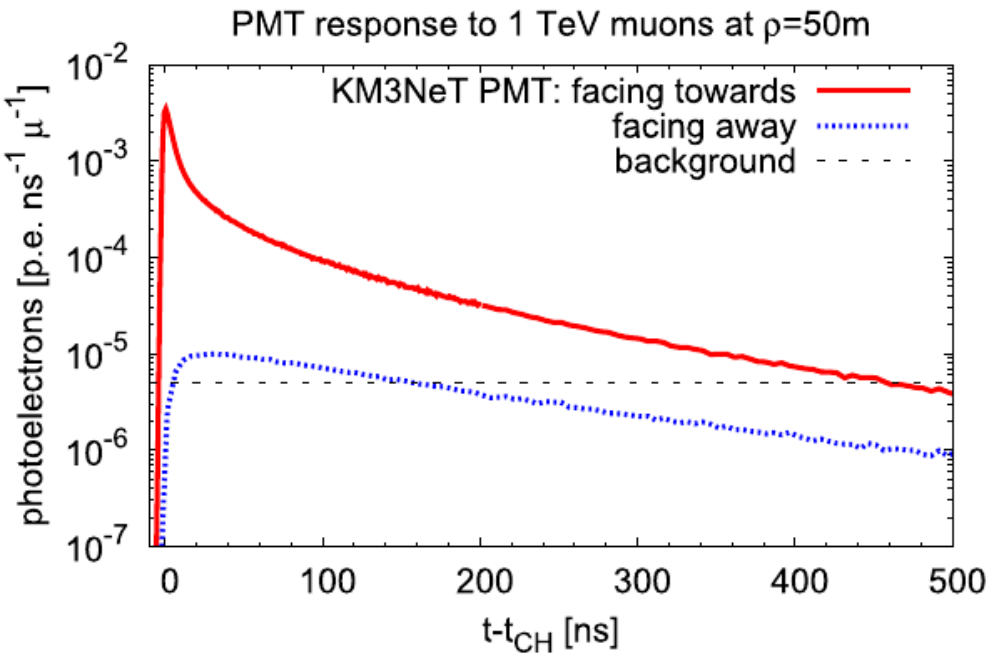


- PMT: gain 10^6
- PMT: compare amount with IceCube: 1:31
- Acoustics: resolution to 20 cm $\mapsto$ 1 ns

DOM Data

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



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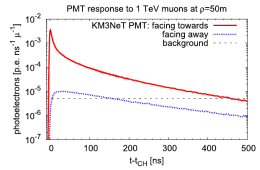

uplink: 25 Gb/s $\mapsto$ reduction of data by 10^5

- DOM uplink 1Gbps

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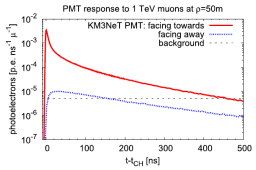

Calibration

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

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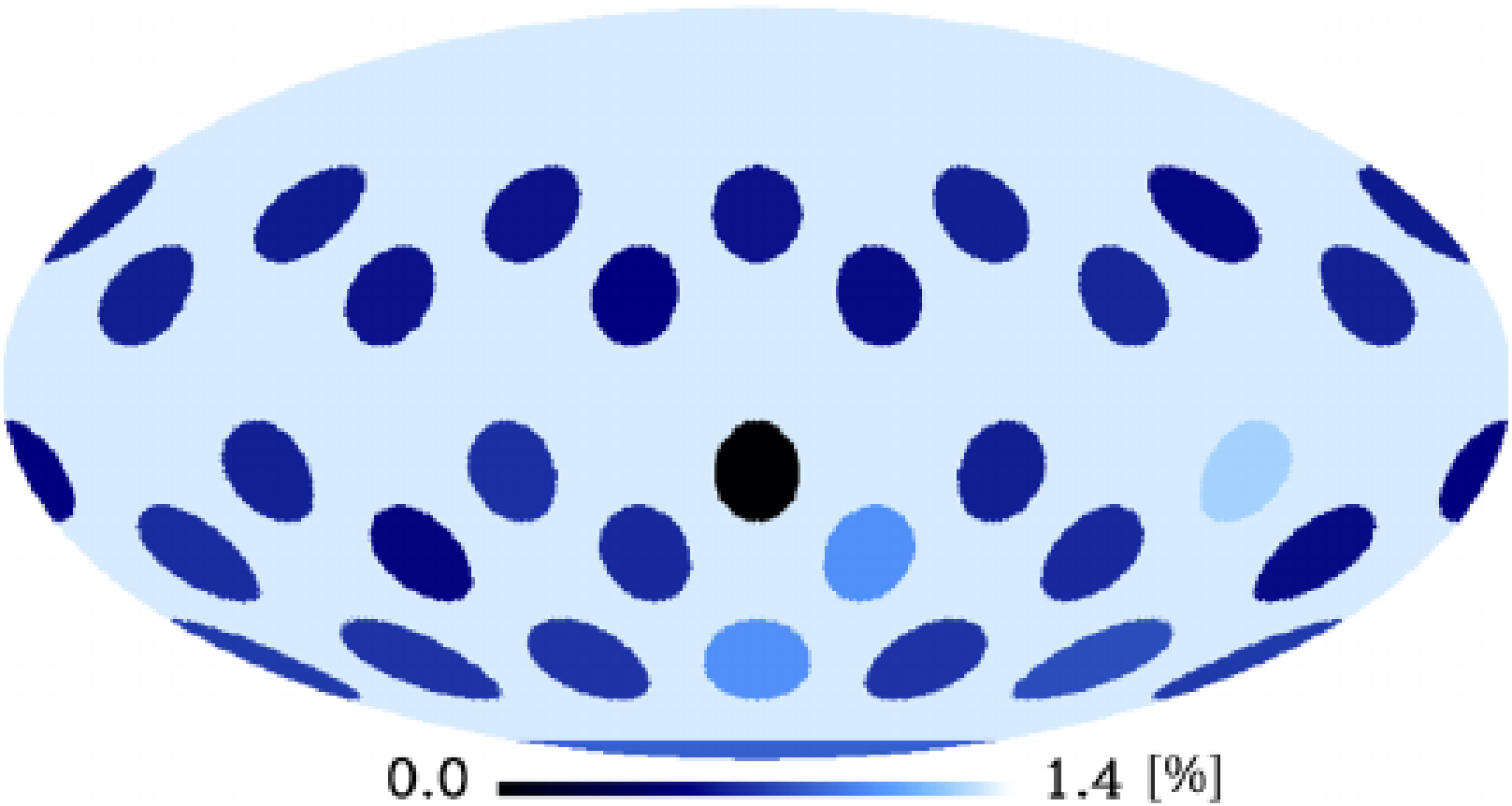
  - Time between DOMs

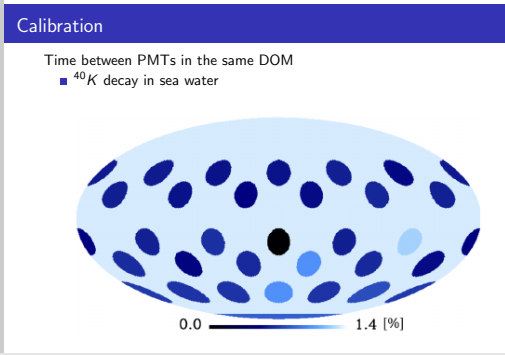
- 8ns data
- $1\mathrm{ns} \times c = 30\mathrm{cm} \mapsto \Delta x \approx 2.40\mathrm{m}$

Calibration

Time between PMTs in the same DOM

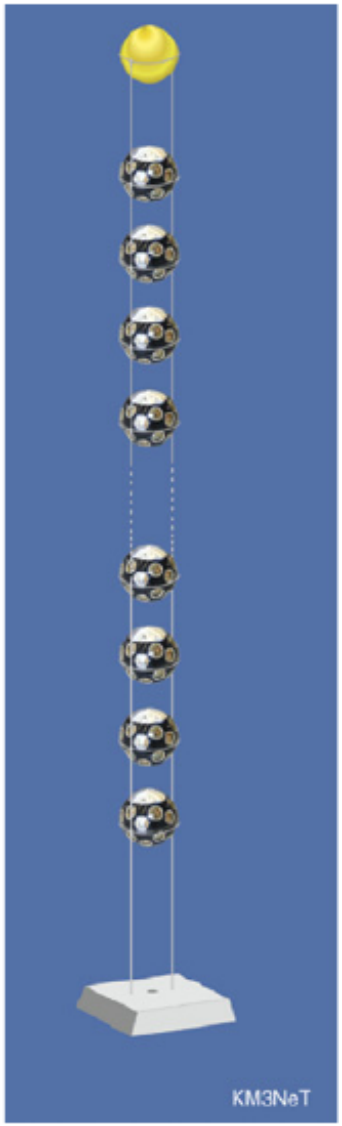
- ^{40}K decay in sea water





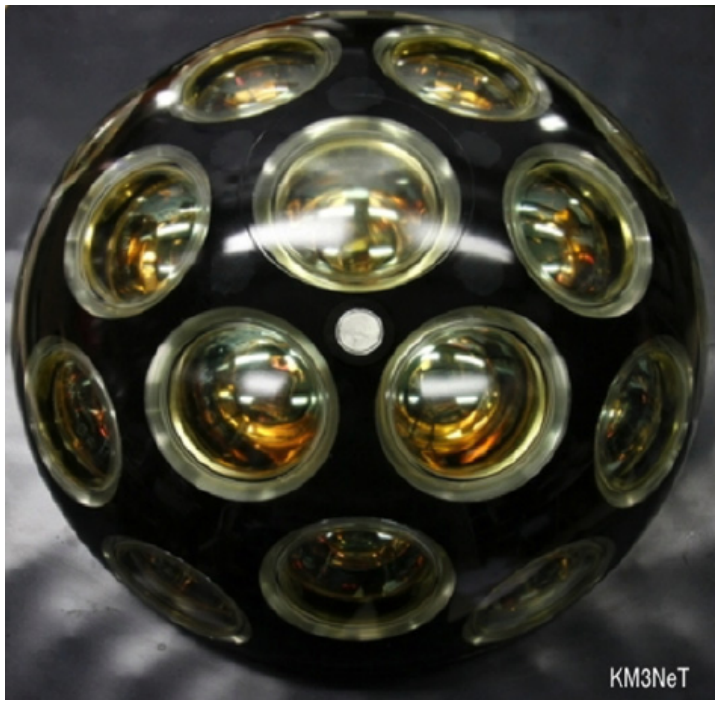
- ^{40}K decay
  - $\lambda_{1/2}$ Gyr
  - 150 Cherenkov γ per decay

Calibration



Time between DOM

- LED nanobeacon
- Acoustic Piezo sensor



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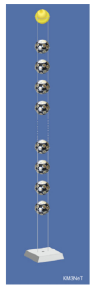

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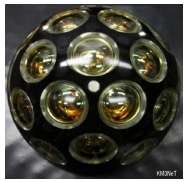


- LED: 470nm, fully controlled from shore (I, f)
- comparison of timings on the same string
- Acoustics: position calibration

Background Effects

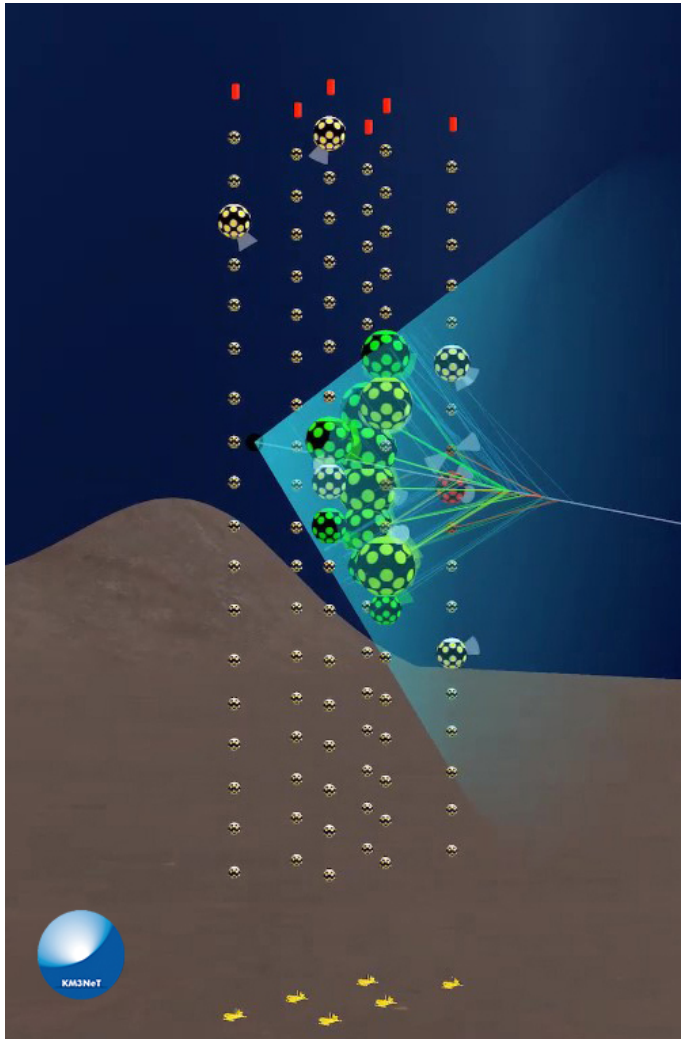
- ^{40}K decay in seawater
- Bioluminescence
- Dust in water

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

Event Triggers

Multiple Triggers

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



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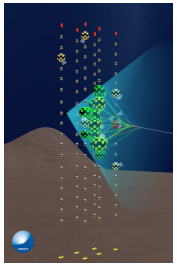
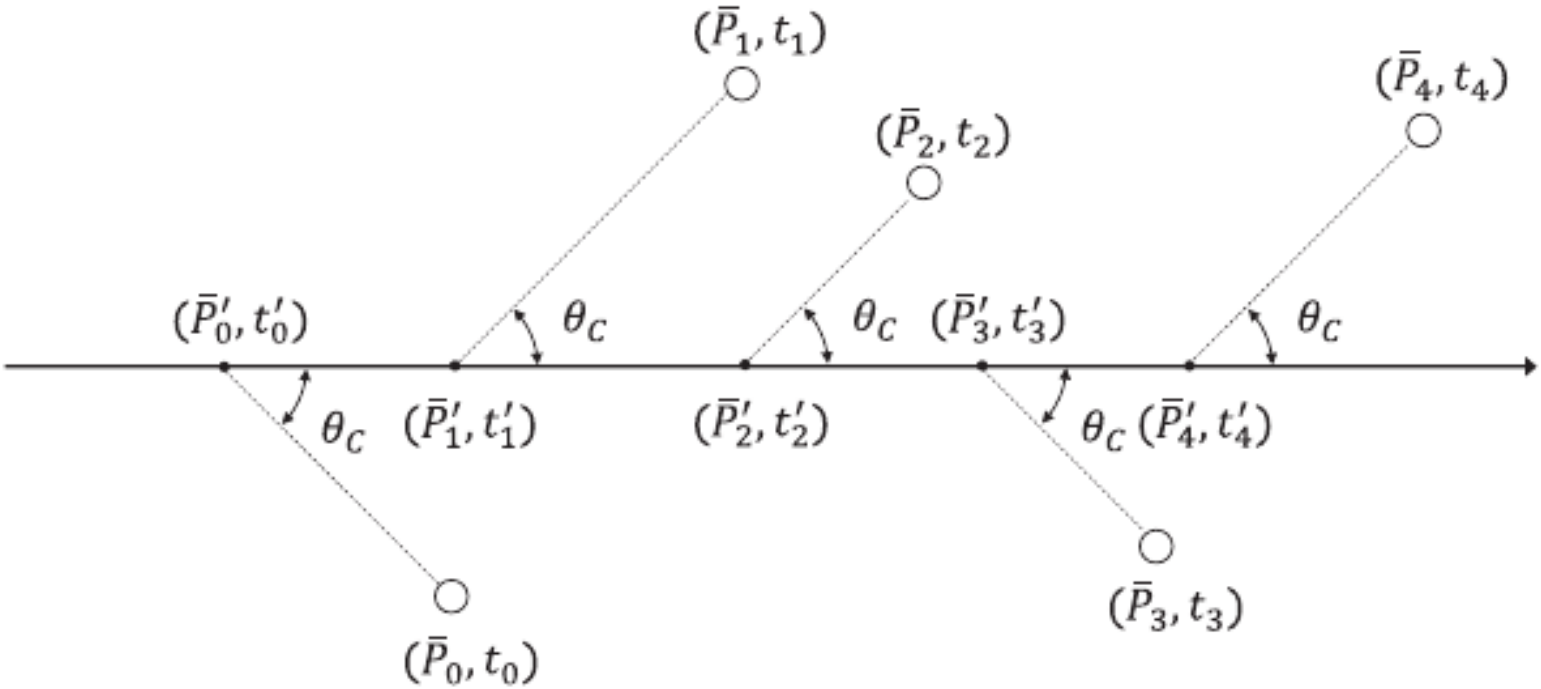


- L1:
  - 1kHz per DOM of which 0.6 is ^{40}K decay.
  - study gives relative time offset mostly 10 ns.
- L2: halves the remaining hits
- Causality: $25\mathrm{ns} \mapsto 7.5\mathrm{m}$

Event Triggers: Muon Tracks and Showers



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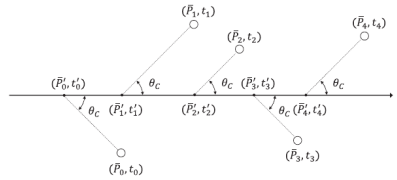
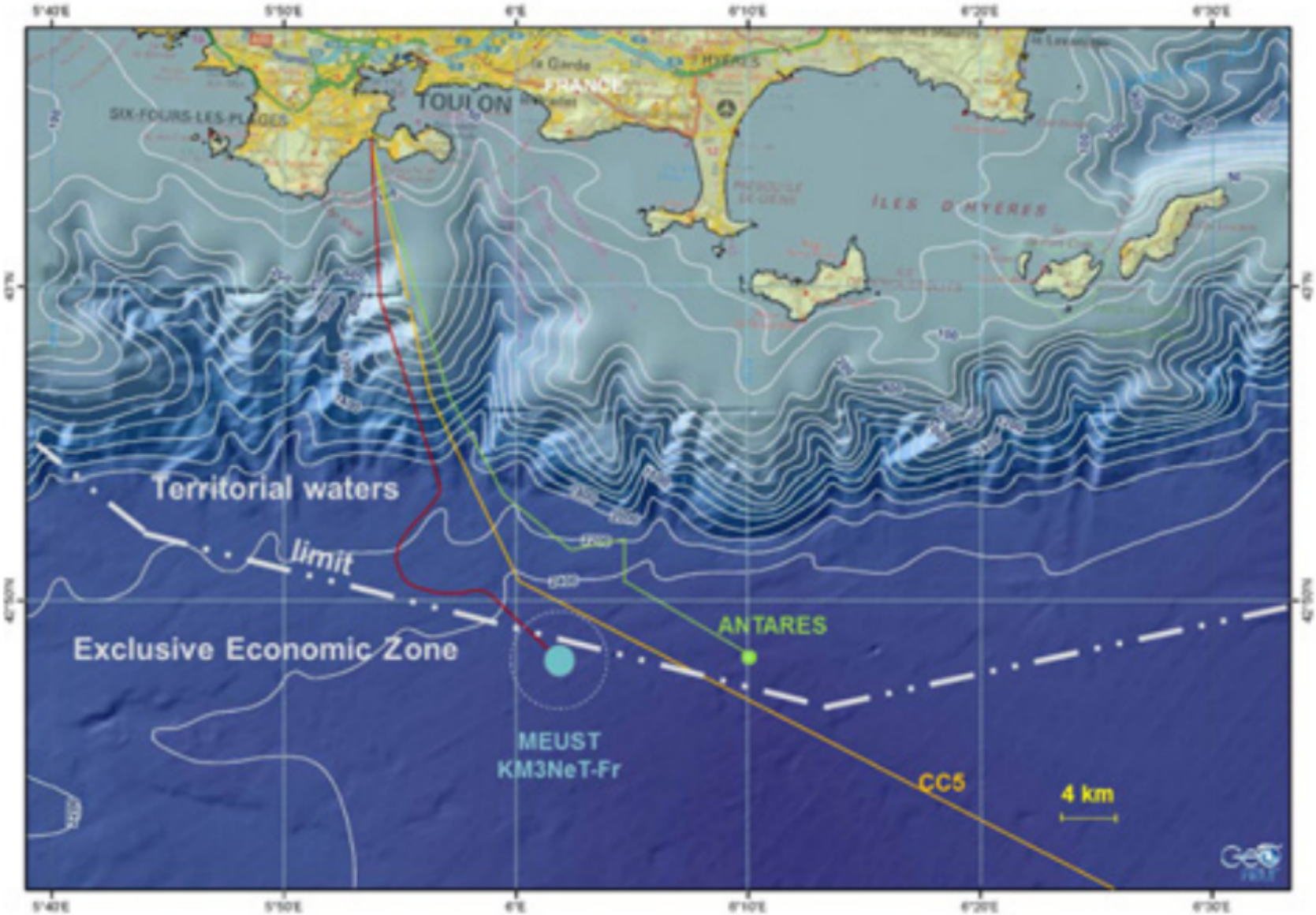


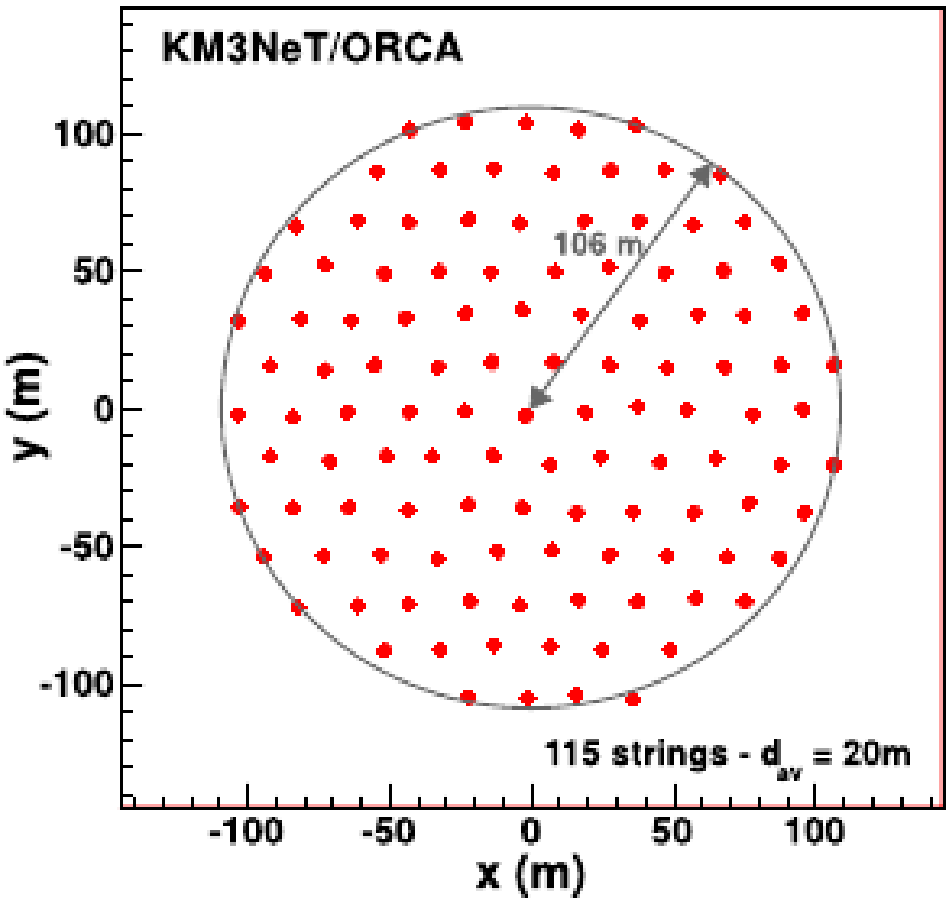
- Various Trigger Algorithms
- Muon track
- directional filter $\sim 10^\circ \mapsto$ 200 directions cover 4π
- shower events

ORCA - Particle Physics



ORCA - Particle Physics

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



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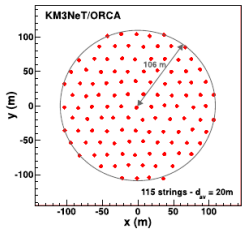
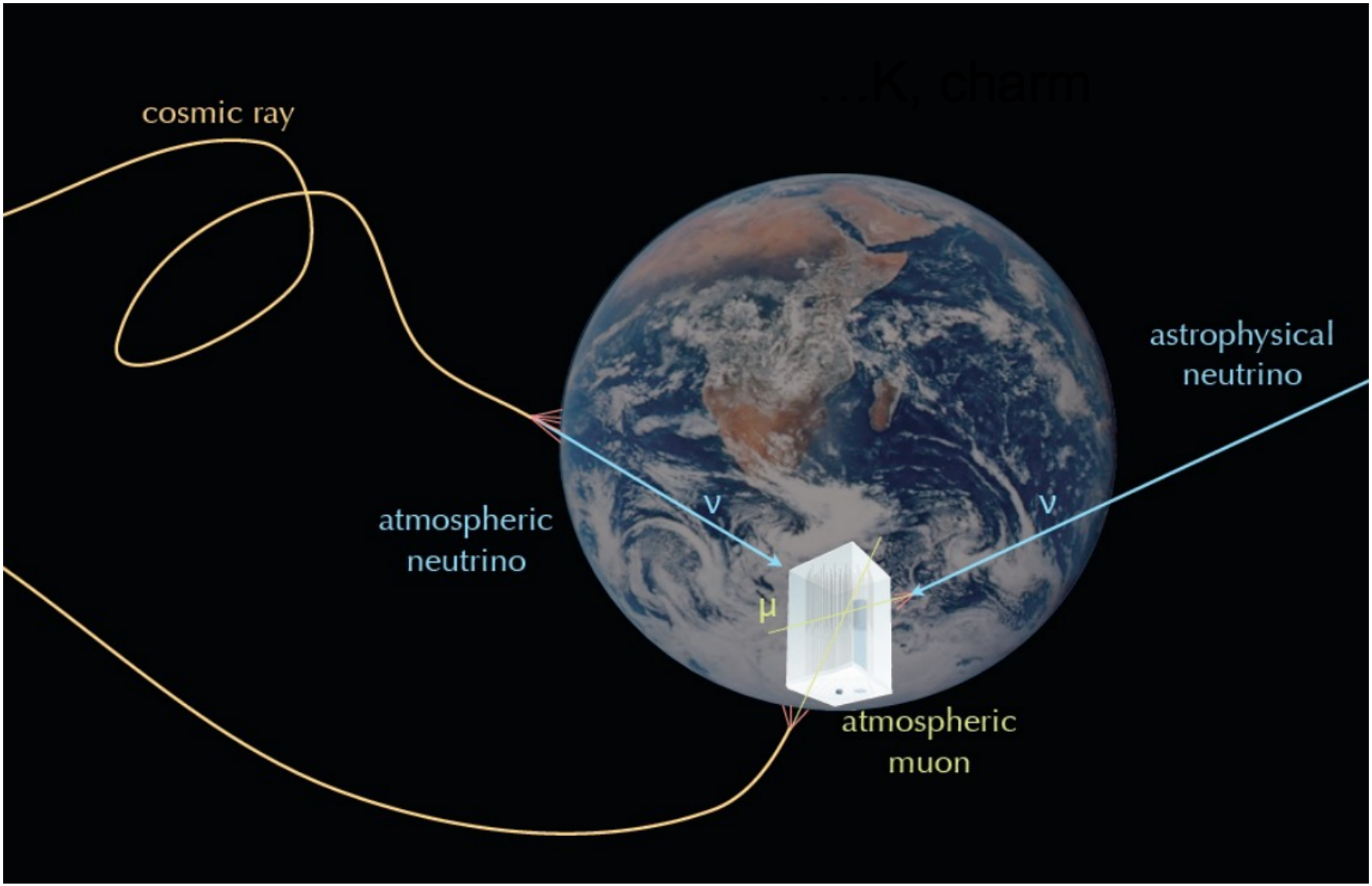
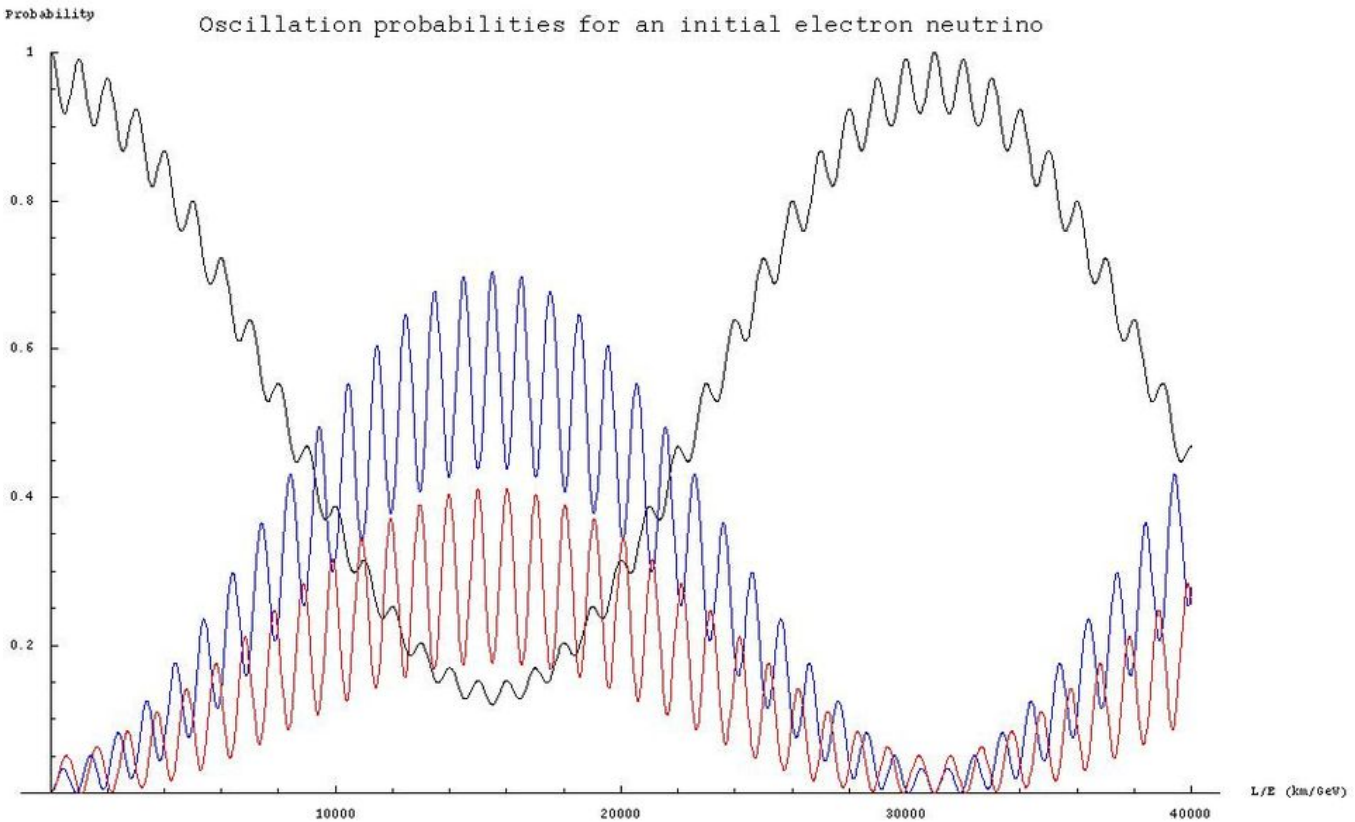


- depth: 2500m
- height: 150m
- width: *see frame*
- instrumented volume: 8 Million tonnes of water
- horizontal distance 20m
- vertical distance 6m


cosmic ray
...K, charm
astrophysical
neutrino
atmospheric
neutrino
ν
ν
μ
atmospheric
muon

Neutrino Oscillations

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



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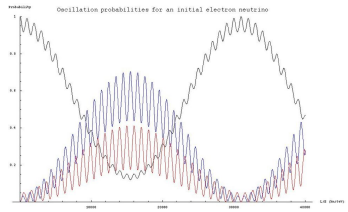
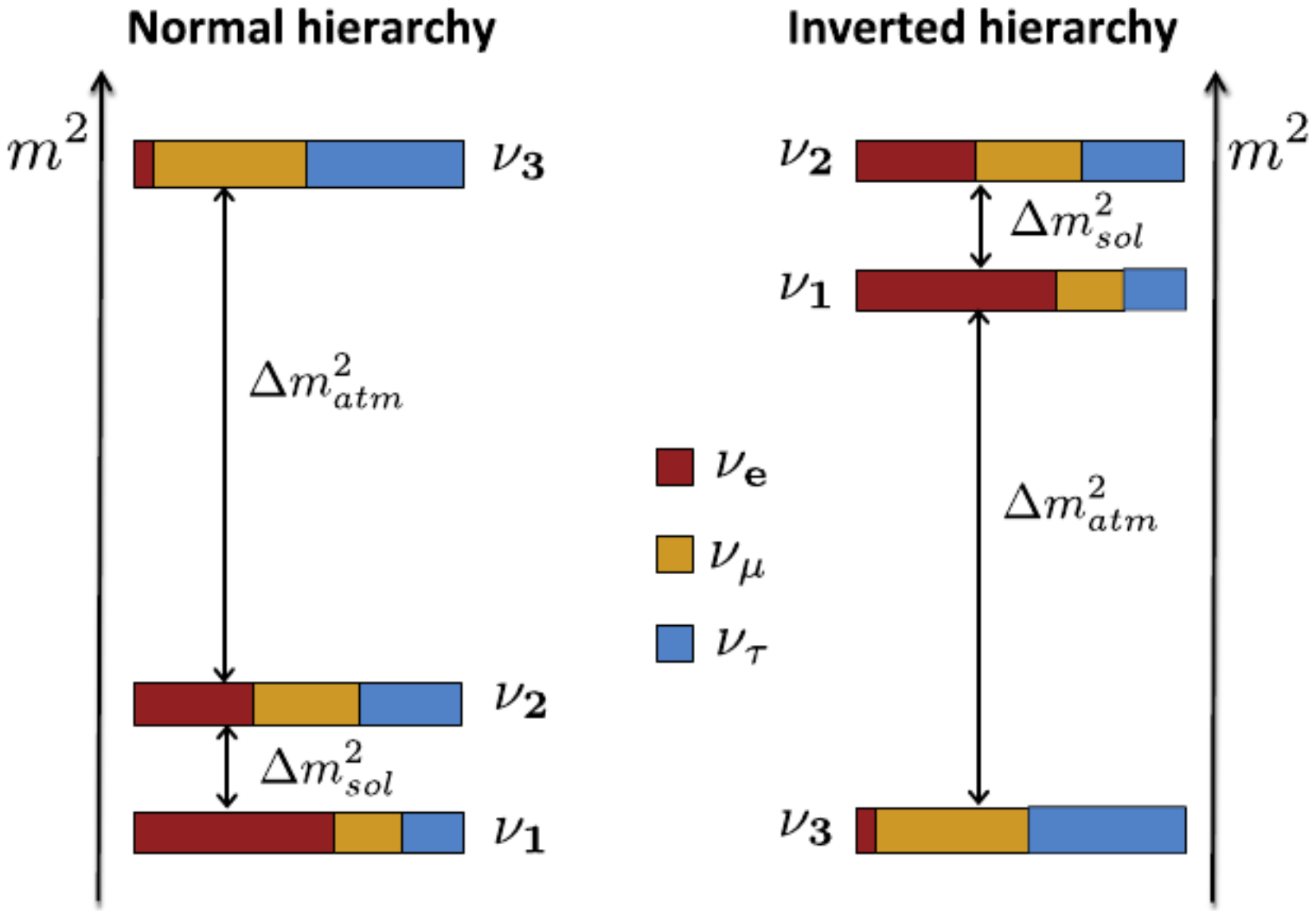
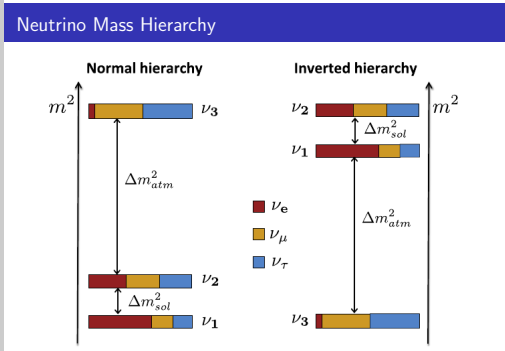


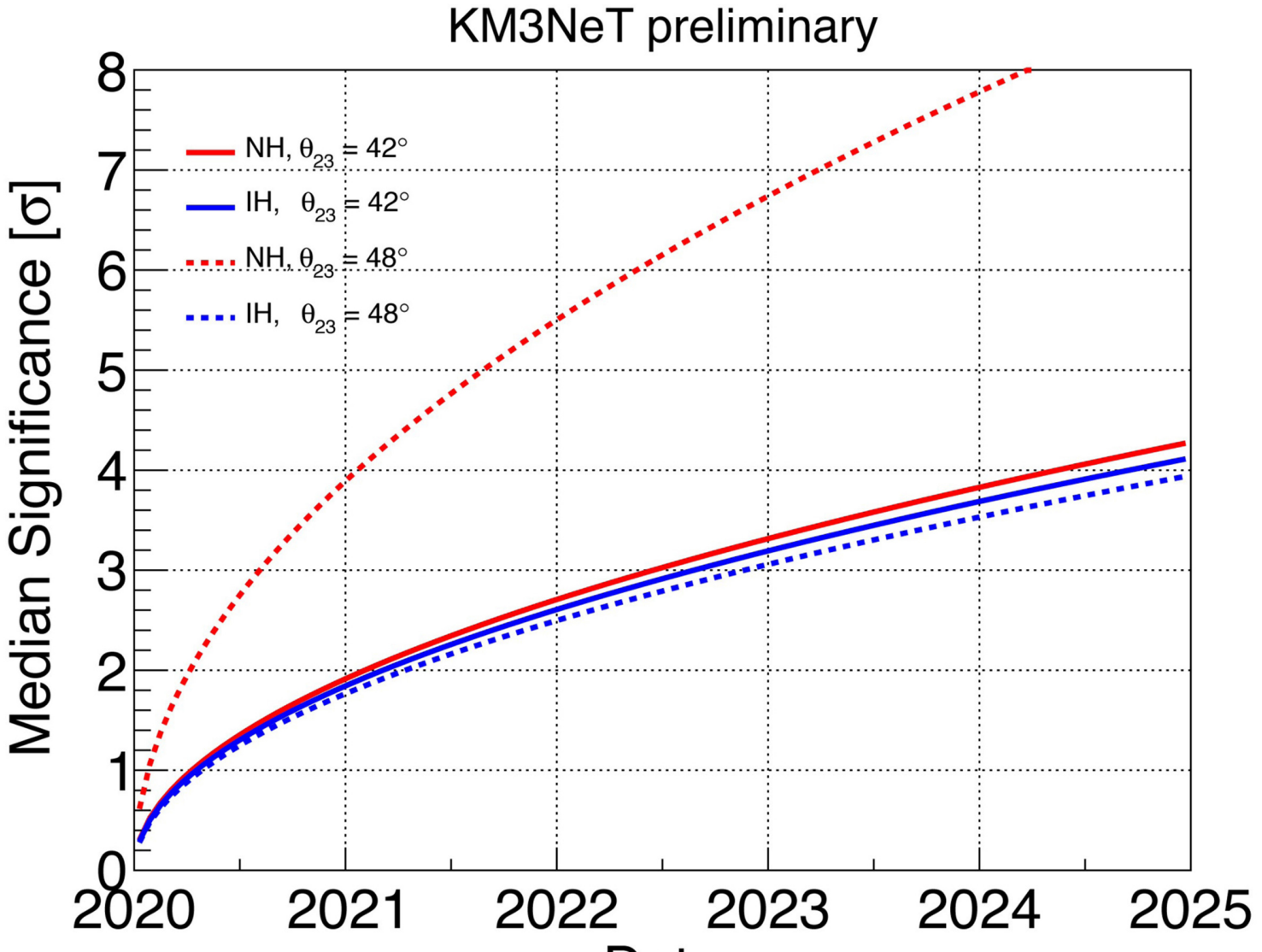
- solar neutrino puzzle
-
- mass eigenstates $\neq$ flavour eigenstates, mass squared diff

Neutrino Mass Hierarchy

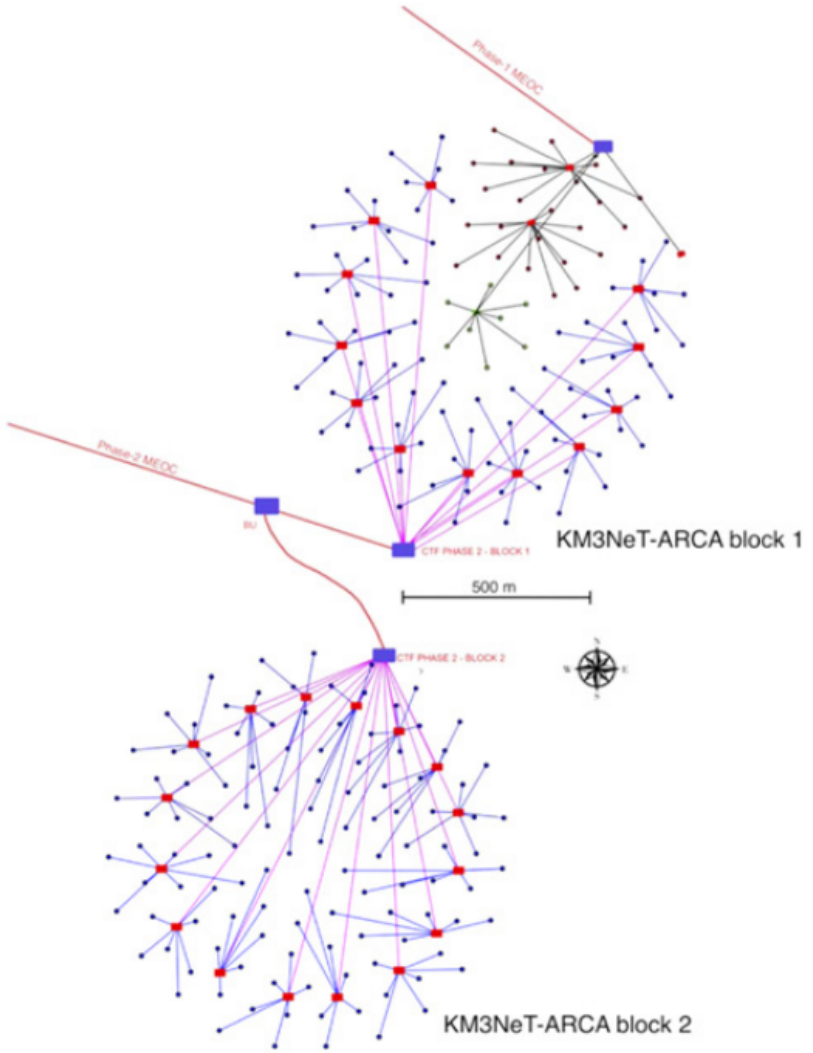




- vaccum oscillations insensitive to sign of mass sq. diff.
- matter is sensisitive $\mapsto$ different cross-sections for ν and $\bar{\nu}$
- effect largest for $E_\nu \approx 30 GeV/\rho \mapsto 1 - 20 GeV$ in KM3NeT
- cannot measure charge
- $\sigma(\nu N) \approx 2\sigma(\bar{\nu} N)$


KM3NeT preliminary
Median Significance [σ]
NH, θ23 = 42°
IH, θ23 = 42°
NH, θ23 = 48°
IH, θ23 = 48°
0
1
2
3
4
5
6
7
8
2020
2021
2022
2023
2024
2025

ARCA - Astroparticle Physics



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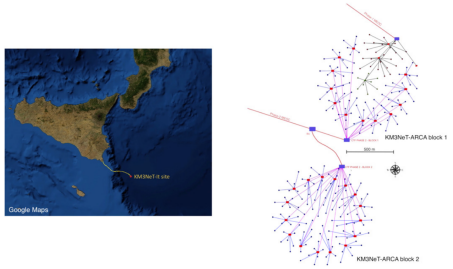
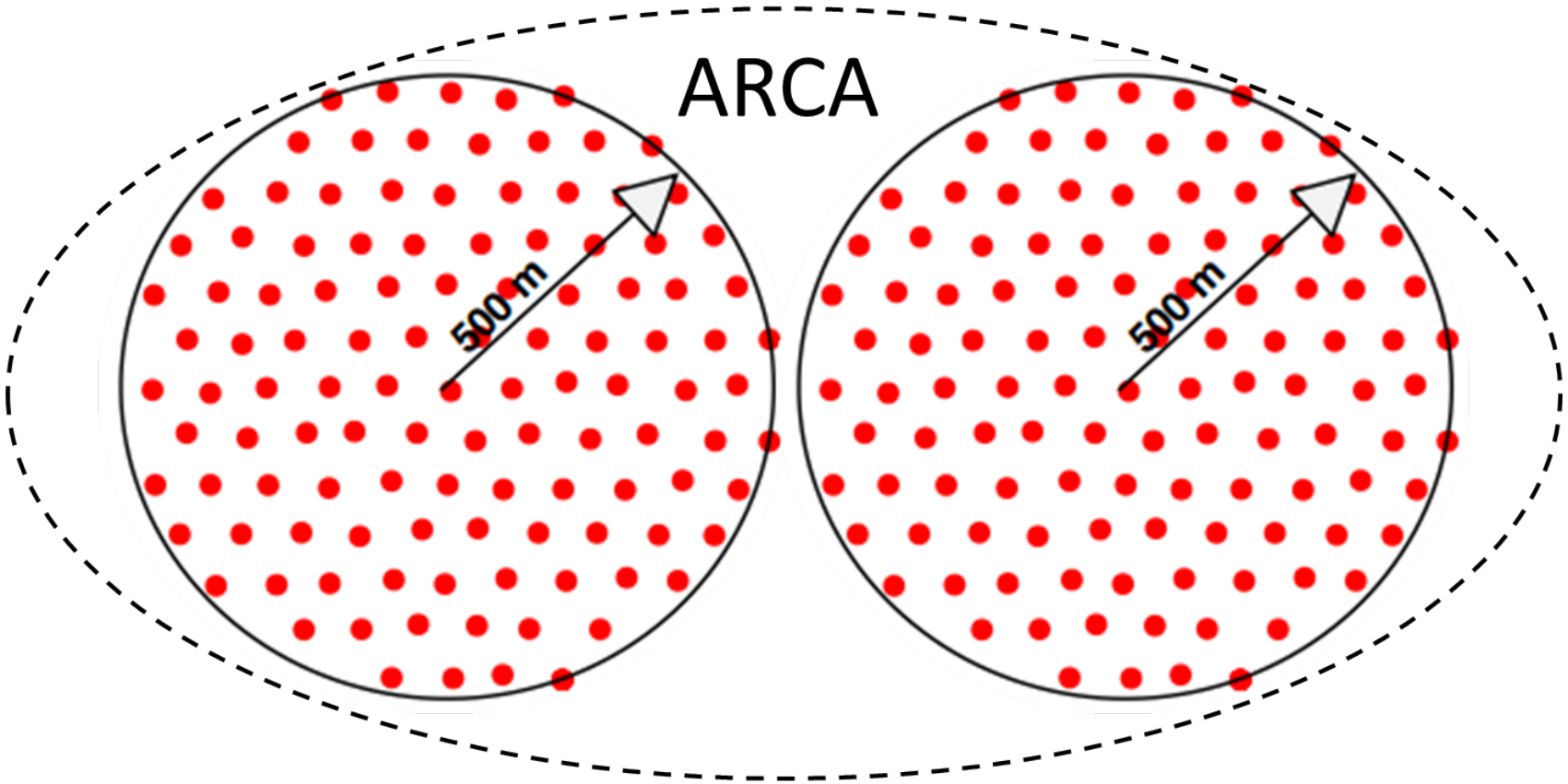
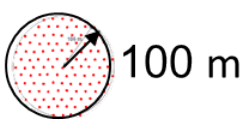


- horizontal distance 90m
- vertical distance 36m
- depth 3.5km

Differences between ARCA and ORCA



ORCA

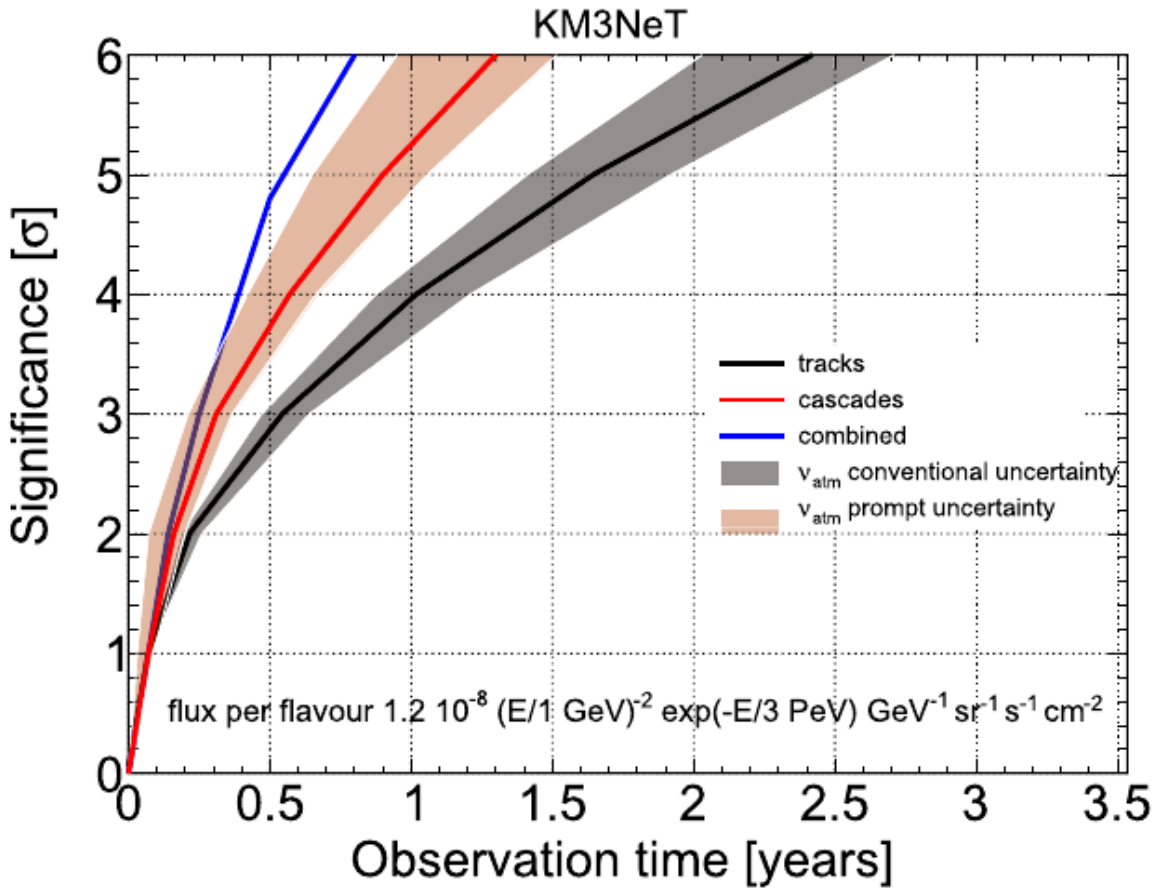


IceCube and Expected Signal

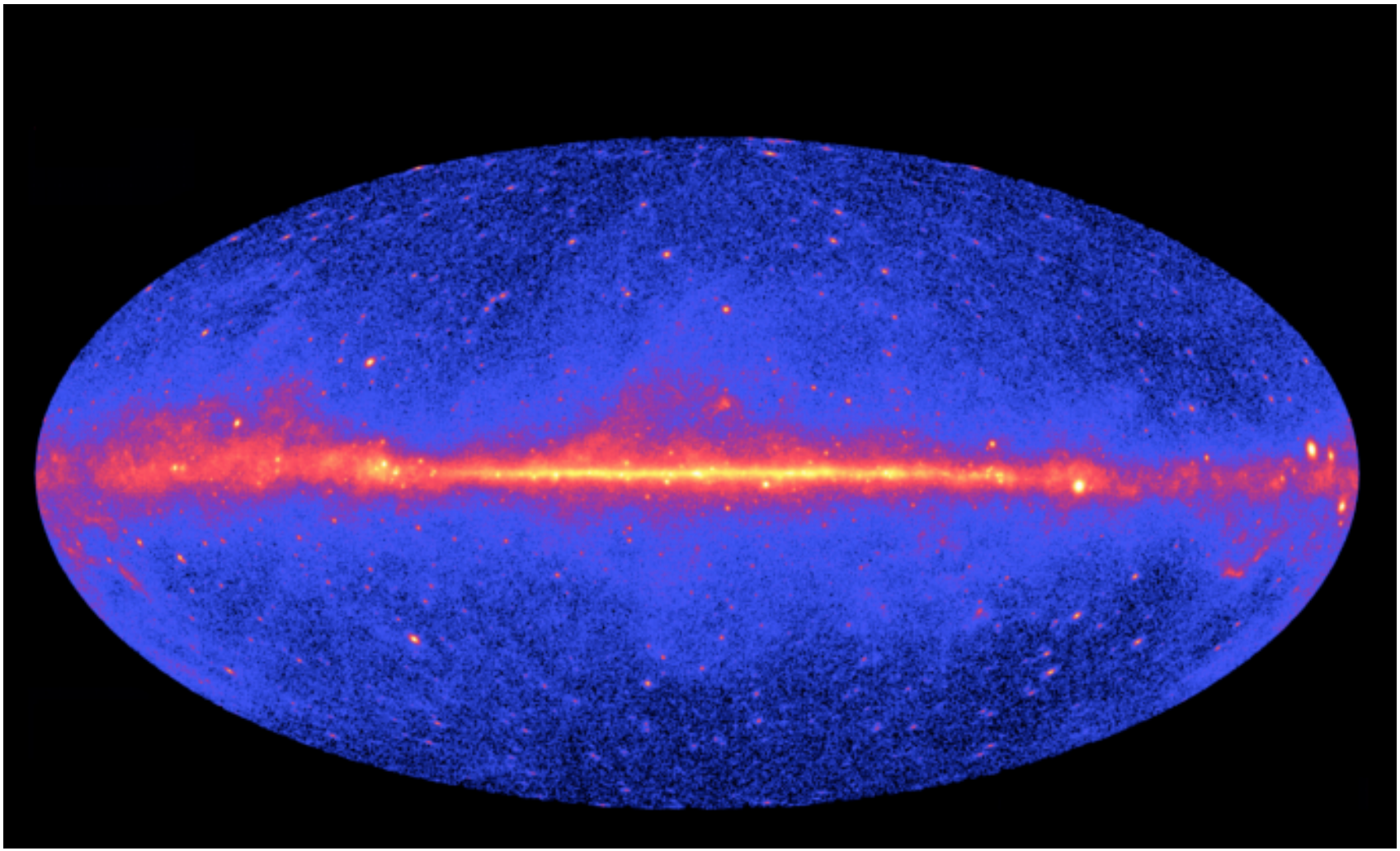
- Signals from 10 TeV to above 1 PeV
- 54 events with reconstructed energy above 30TeV (2016, IceCube)

IceCube and Expected Signal

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



Expected Signals: Diffuse Flux from Galactic Plane



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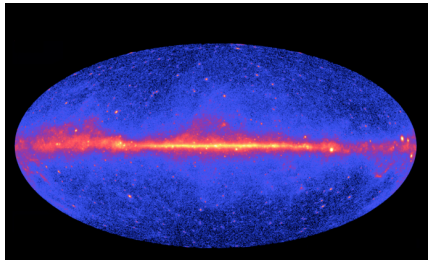
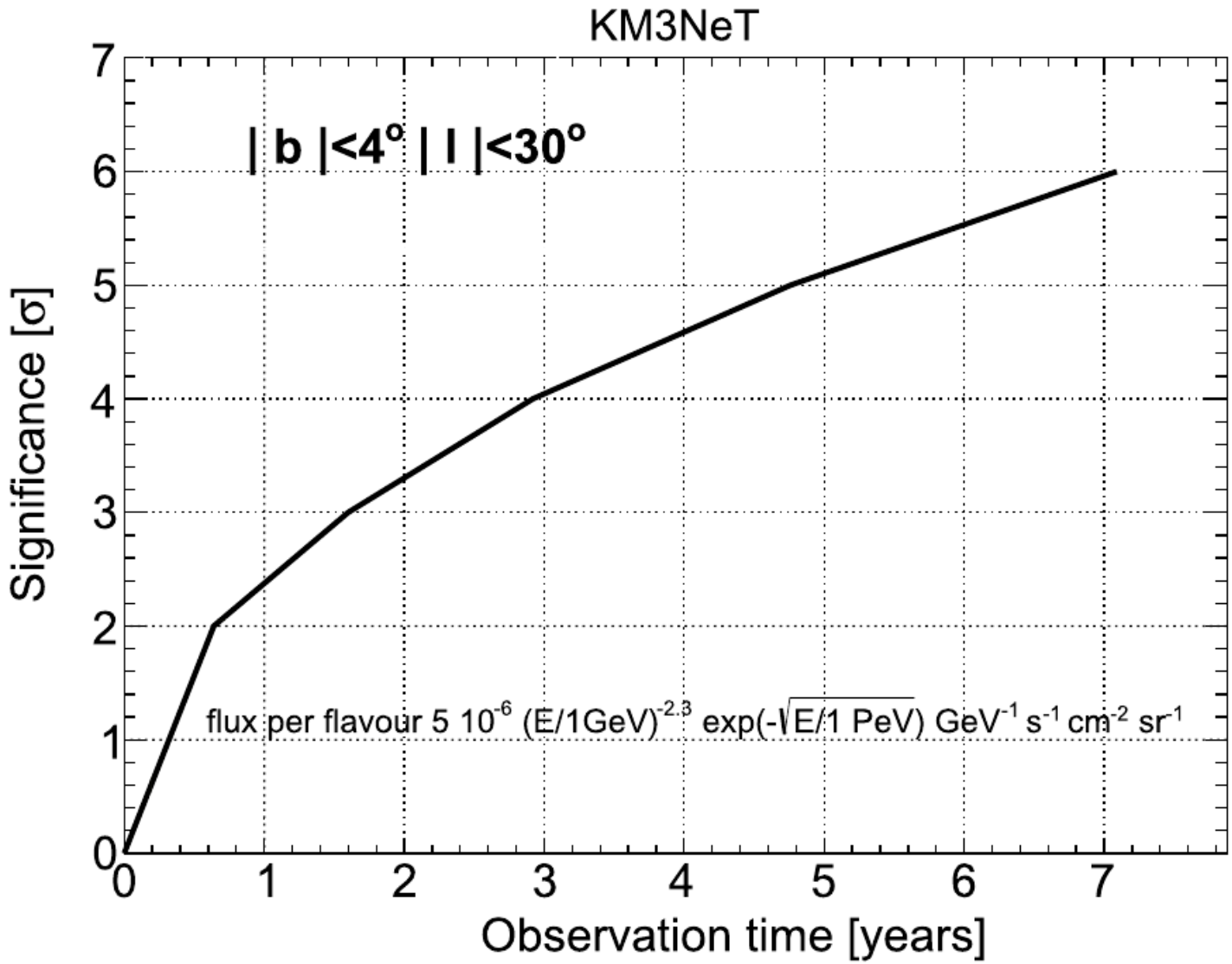


- TeV γ-ray emmission from GP
- same hadronic processes lead to high-energy ν's

Expected Signals: Diffuse Flux from Galactic Plane



Expected Signals: Point like sources

- Good Angular Resolution
- Galactic Sources can be probed

Recap

- 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

Deployment of Strings

https://www.youtube.com/watch?v=7HKHW0hLxt4&list=PLL9OR_-tW5qOtfZigqVpzMmTSwkMjCT1s&index=8