KM3NeT: Status and perspectives

J. Barrios-Martí, on behalf of the KM3NeT collaboration

TeVPA 2016

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KM3NeT

IFIC INSTITUT DE FÍSICA CORPUSCULAR

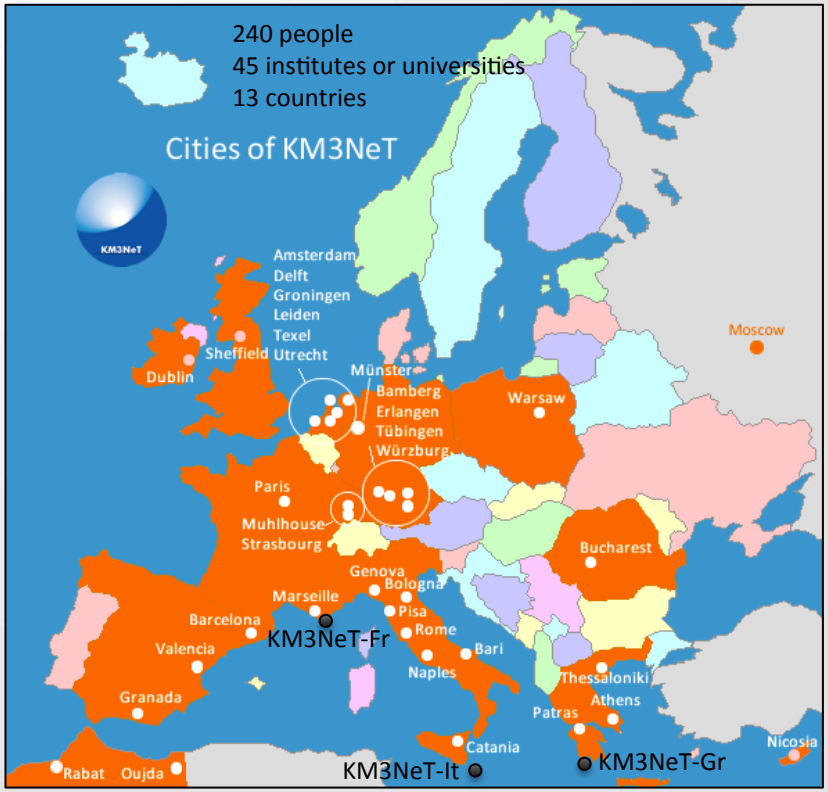
VNIVERSITAT DE VALÈNCIA

CSIC CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

The KM3NeT project

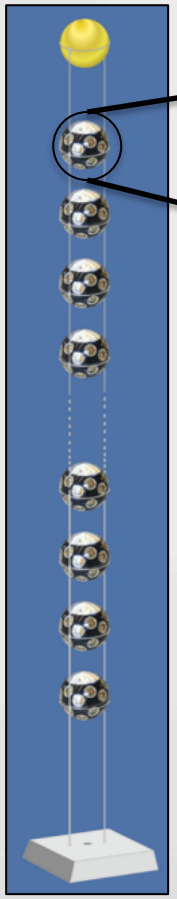
- KM3NeT
  - Deep sea neutrino telescopes in the Mediterranean Sea
  - Ideal location for observation of sources of our Galaxy

- Main objectives:
  - Discovery and observation of high-energy neutrino sources of cosmic origin **(KM3NeT/ARCA)**
  - Determination of neutrino-mass hierarchy **(KM3NeT/ORCA)**
- Main objectives, detector description and performance thoroughly described in our Letter of Intent
  - Published in [J. Phys G: Nucl. Part. Phys. 43 084001](#) (also in [arXiv:1601.07459](#))



The KM3NeT research infrastructure

- Detection principle: Observation of high energy neutrinos by the Cherenkov radiation produced by leptons from neutrino interactions by a 3D PMT array.



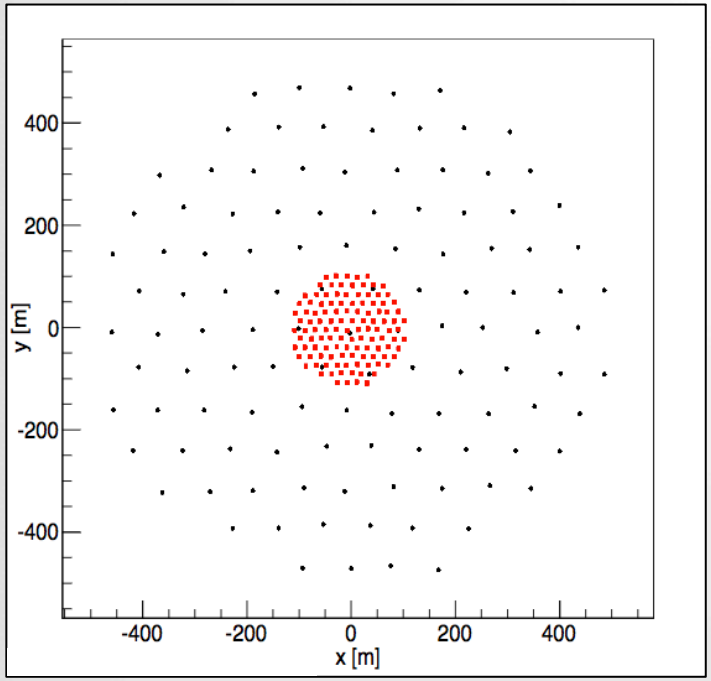
DOM (digital optical module)

- 17'' diameter glass sphere.
- 31 PMTs of 3'' each.
- Records time and Time over Threshold of each detected hit.
- FPGA.
- LED & piezo inside.
- Compass and tilt-meter.

DU (Detection Unit)

- 18 DOMs
- KM3NeT/ARCA
  - **36 m distance between DOMs**
  - **700 m high**
- KM3NeT/ORCA
  - **9 m distance between DOMs**
  - **150 m high**

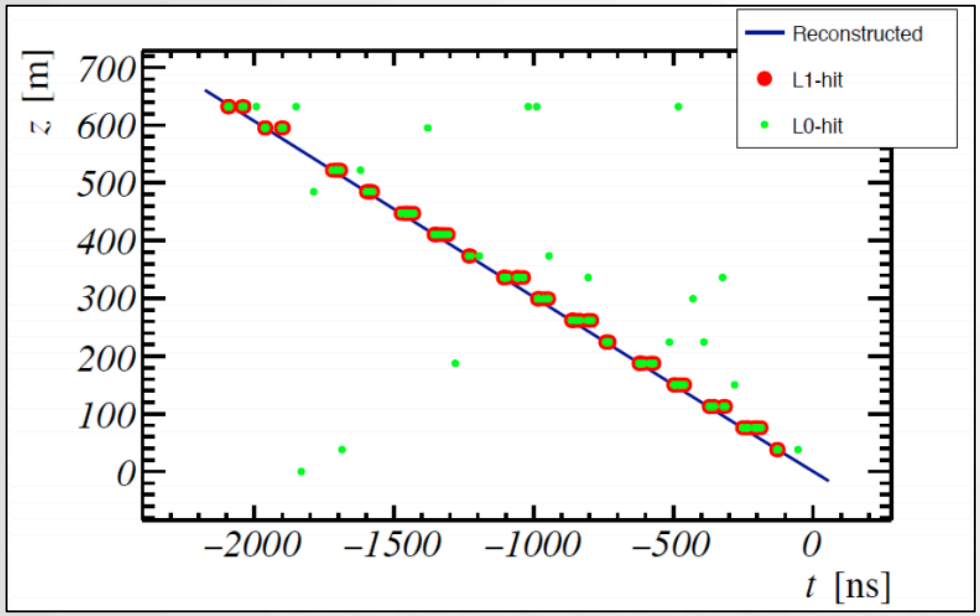
The KM3NeT research infrastructure



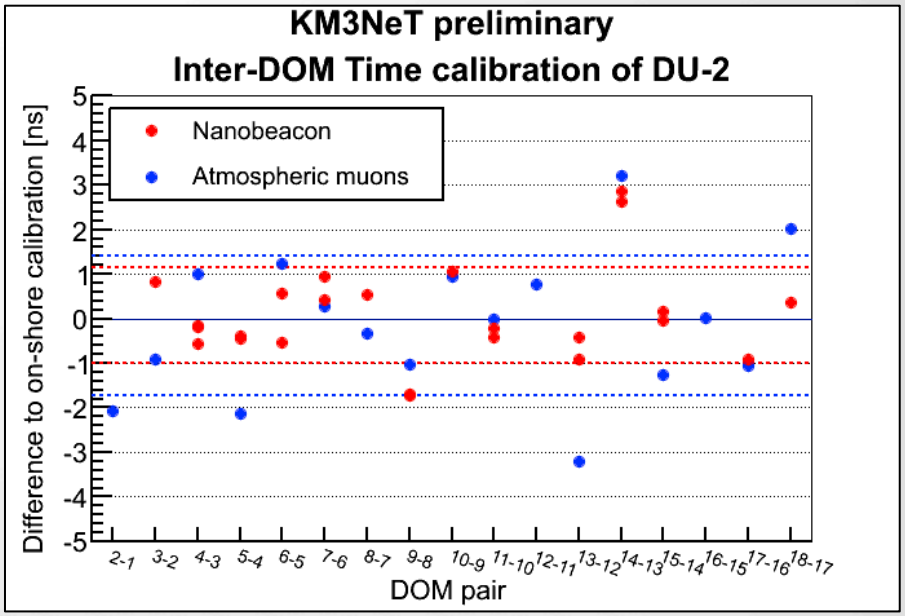
Example of a building block for ORCA (red) and ARCA (black). Both building blocks are made of 115 DUs.

	ARCA	ORCA
Location	Italy	France
Spacing between lines	90 m	20 m
Spacing between DOMs	36 m	9 m
Instrumented mass	500 Mt (0.5 km^3) per block	5.7 Mt
Blocks (Phase 2)	2	1

Results from first DU deployed on Dec 2015

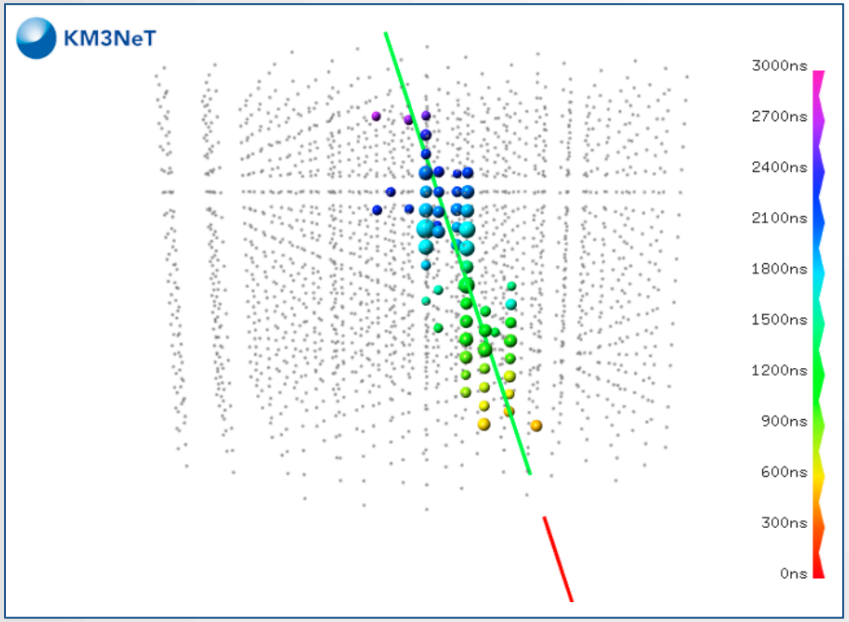


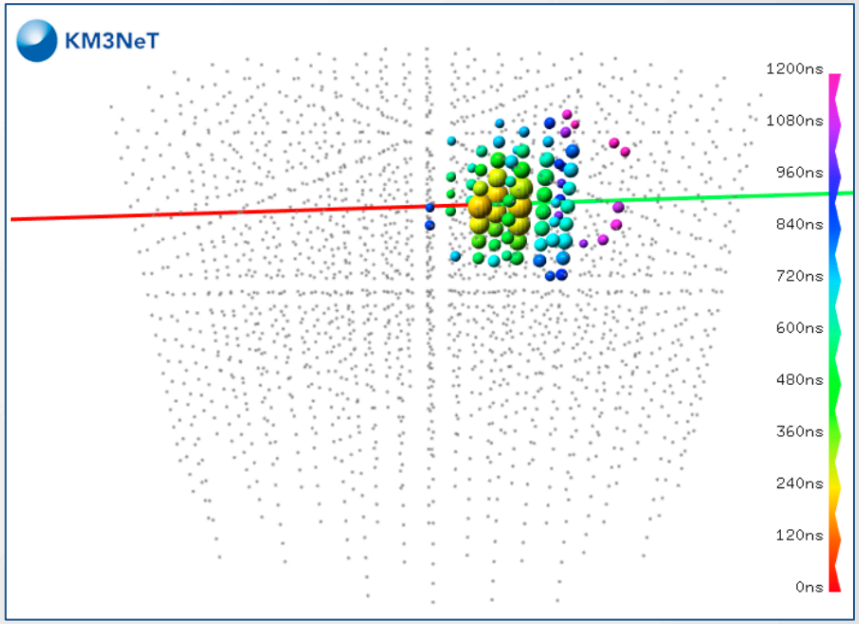
Reconstructed down-going muon with first deployed DU.



Time calibration with nanobeacons (red) and atmospheric muons (blue) performed on the first DU

KM3NeT/ARCA: Event types



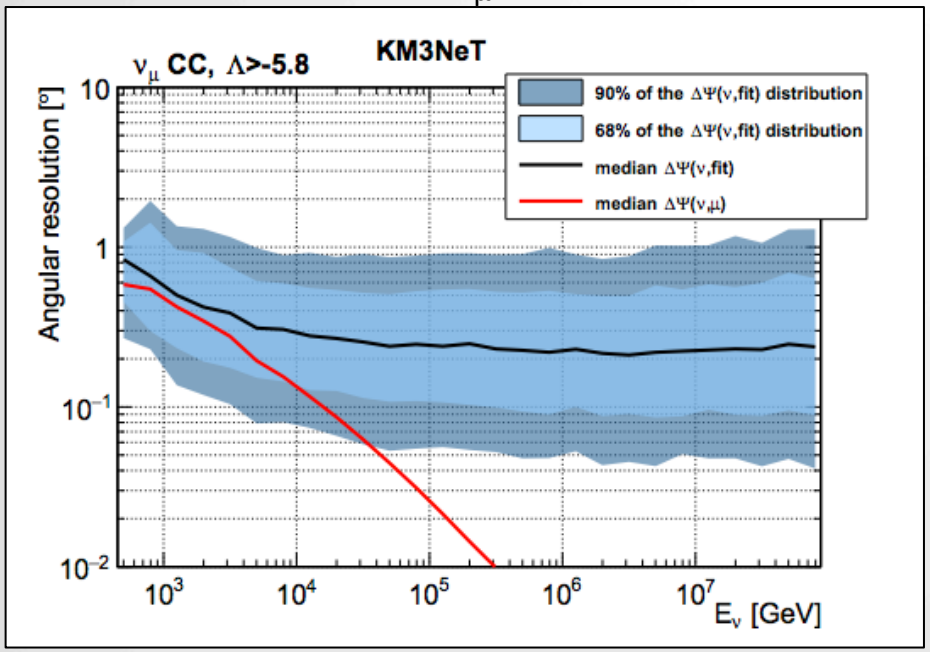


- Track events
  - Produced by ν_μ and some ν_τ by CC interaction.
  - Ang. Resolution ~0.2° for $E_\upsilon > 10^5$ GeV.

- Cascade events
  - Produced by ν_e and some ν_τ via CC interactions, and all flavours via NC interaction.
  - Ang. Resolution of ~2°

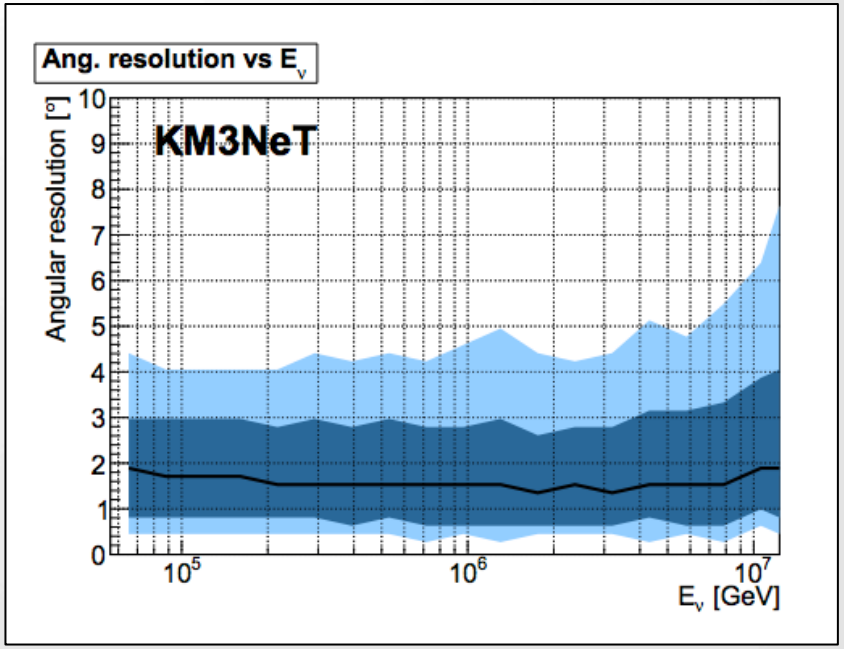
Performance for ARCA: Angular resolution

Track-like: ν_μ CC events



Median angular resolution of ~0.2° for energies above 10^5 GeV ($\Lambda > -5.8$)

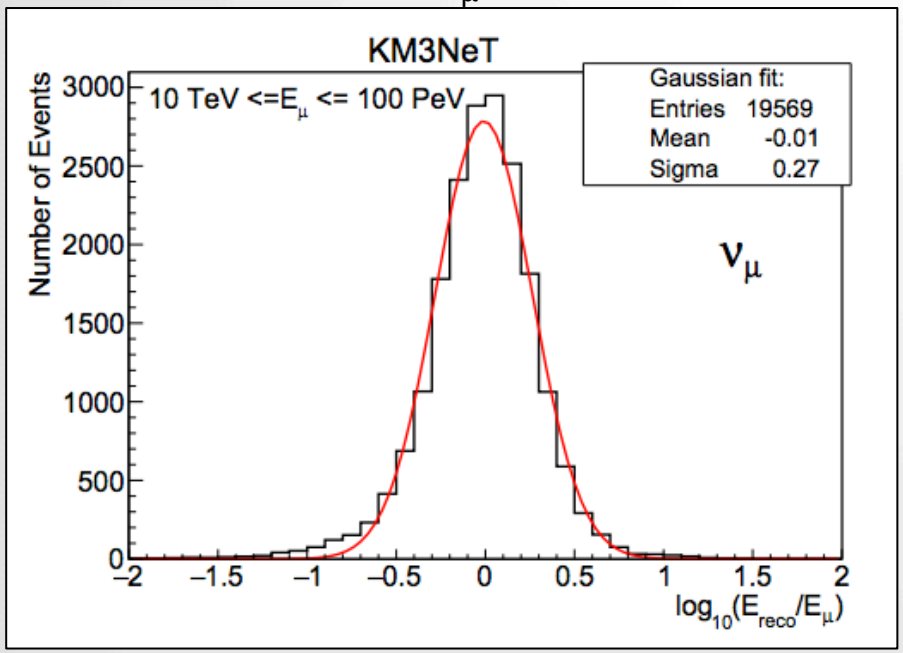
Cascade-like: ν_e CC events



Median angular resolution of <2° for energies above 10^5 GeV (z_{reco} < 200 m, r_{reco} < 500 m, ToT_{evt} > 12 μs)

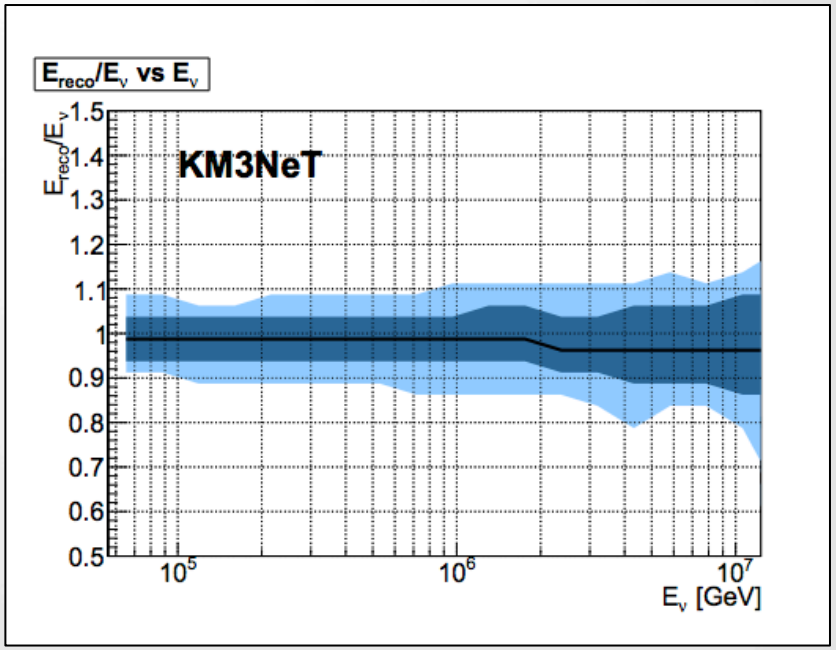
Performance for ARCA: Energy resolution

Track-like: ν_μ CC events



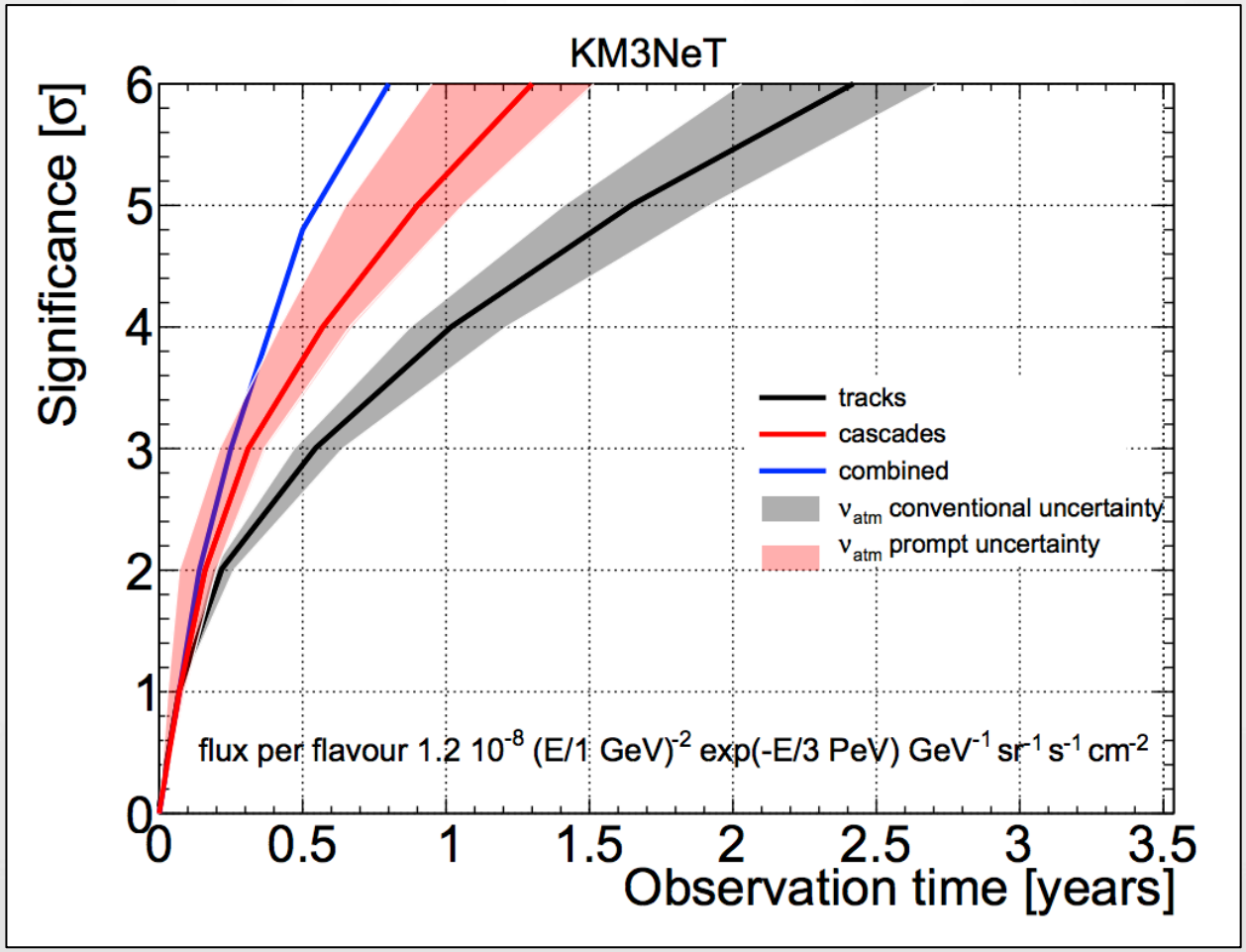
Energy resolution of 0.27 in $\log_{10}(E)$

Cascade-like: ν_e CC events



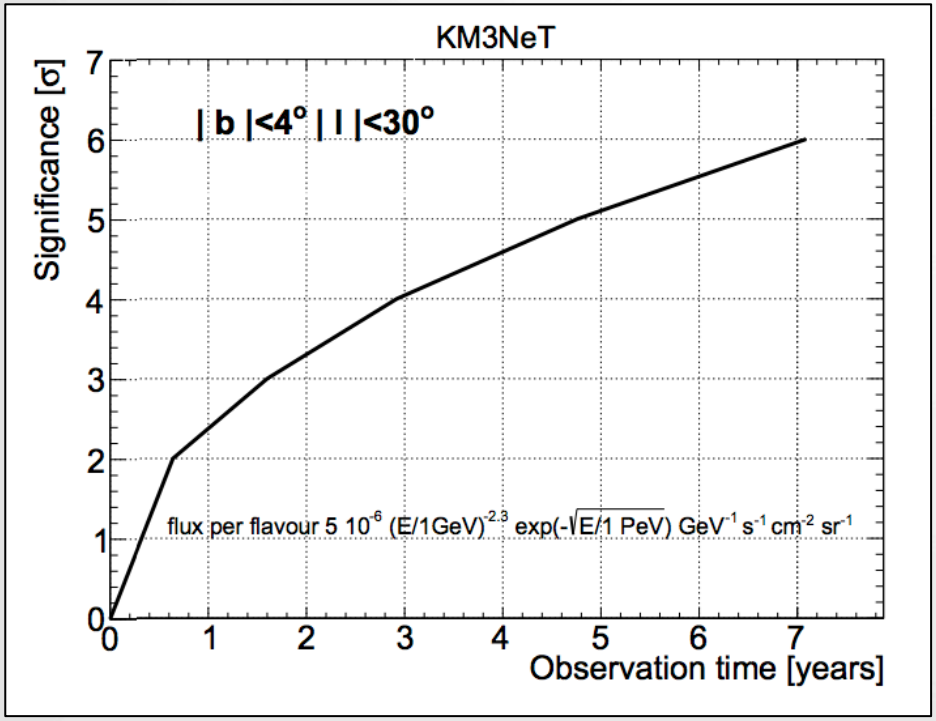
Energy resolution of ~10% (z_{reco} < 200 m, r_{reco} < 500 m, ToT_{evt} > 12 μs)

KM3NeT/ARCA: Isotropic diffuse flux analysis



By combining both samples, the reported flux can be seen with 5σ significance in 0.6 years!

KM3NeT/ARCA: Diffuse flux analysis around the Galactic Center



Significance estimation over time for the assumed spectra.

- Galactic Plane as potential region of diffuse astrophysical source.
  - D. Gaggero et al., arXiv: 1508.03681 (2015)
- Only muon-track events considered.
- Events selected within the region: |l|<30°, |b|<4°
- 5σ discovery to be achieved after 5 years of operation.

KM3NeT/ARCA: Galactic sources

SNR RXJ1713.7-3946

- 0.6° radius extended source.
- Assumed spectrum:

$$\frac{d\phi}{dE_\nu} = 16.8\times10^{-15}\left[\frac{E_\nu}{1TeV}\right]^{-1.72}\exp\left(\sqrt{\frac{E_\nu}{2.1TeV}}\right)GeV^{-1}cm^{-2}s^{-1}$$

From S. R. Kelner, F. A. Aharonian and V. V. Bugayov, Phys. Rev. D 74, 034018 (2006)

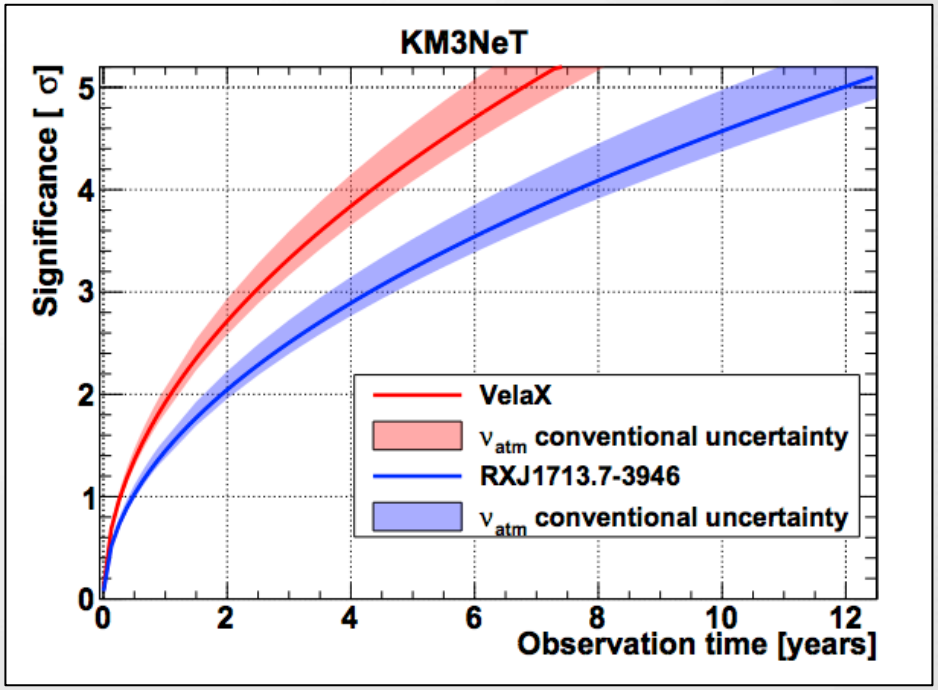
Vela X

- 0.8° radius extended source.
- Assumed spectrum for the source:

$$\frac{d\phi}{dE_\nu} = 7.2\times10^{-15}\left[\frac{E_\nu}{1TeV}\right]^{-1.36}\exp\left(\sqrt{\frac{E_\nu}{7TeV}}\right)GeV^{-1}cm^{-2}s^{-1}$$

F.L. Villante and F. Vissani, Phys. Rev. D 78, 103007 (2008)

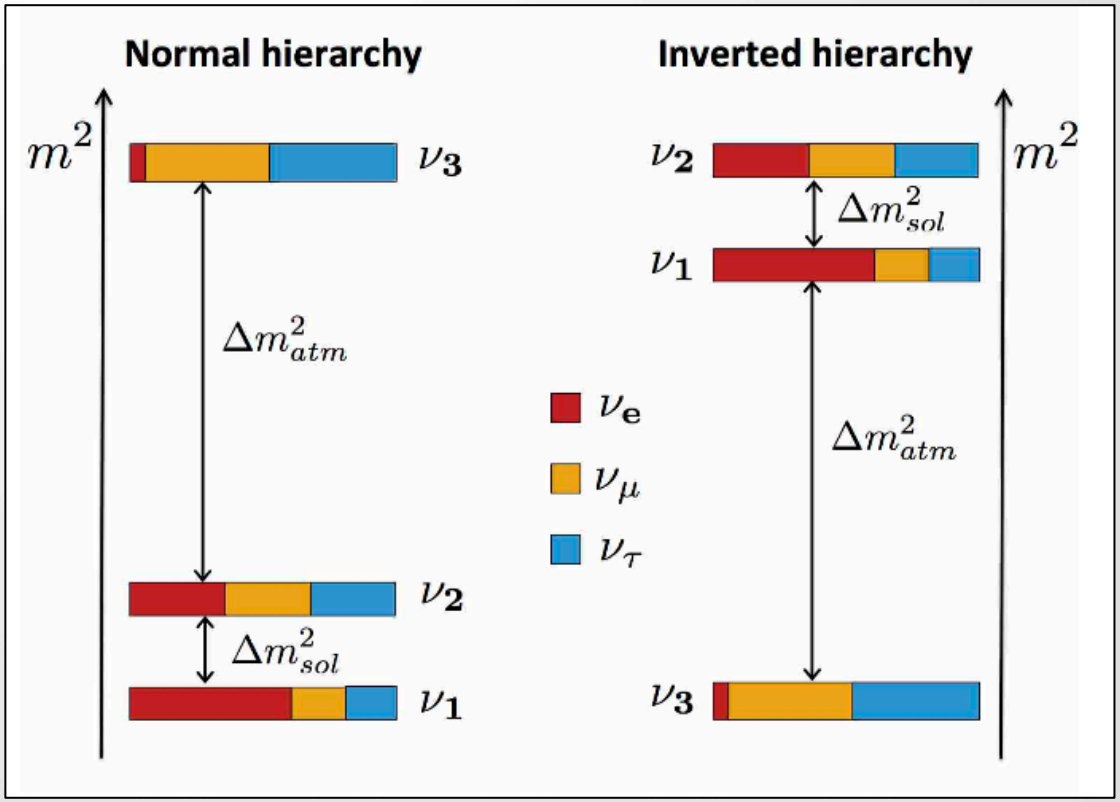
- Procedure:
  - Pre-selection: muon tracks with θ_{rec}>78°.
  - BDT training applied.



Significance of 3σ in less than 3 (5) years for Vela X (RXJ1713.7).

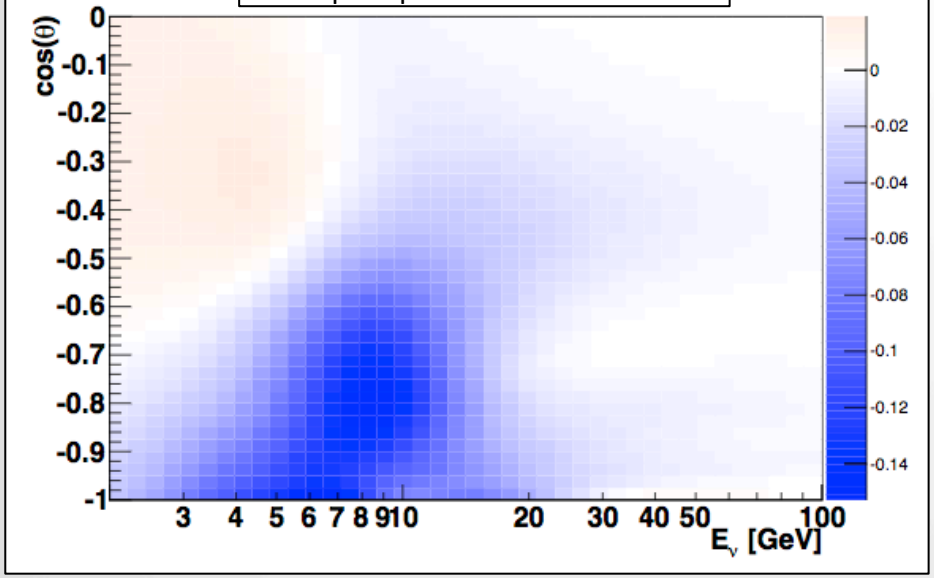
KM3NeT/ORCA: Physics goals

- Determine the **Neutrino Mass Hierarchy (NMH)**
- Precise measurements of the atmospheric neutrino parameters.
- Indirect dark matter searches.

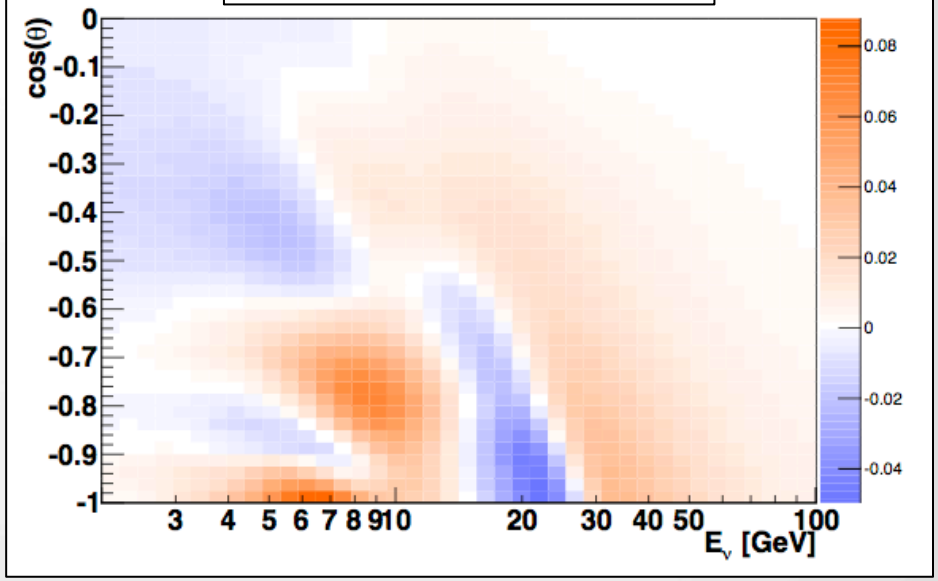


KM3NeT/ORCA: Measuring the NMH

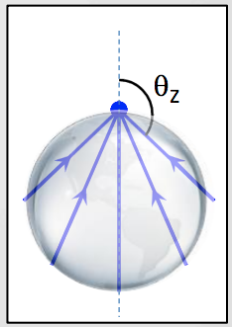
$\upsilon_\mu+\bar{\upsilon}_\mu$ (NH-IH)/NH



$\upsilon_e+\bar{\upsilon}_e$ (NH-IH)/NH



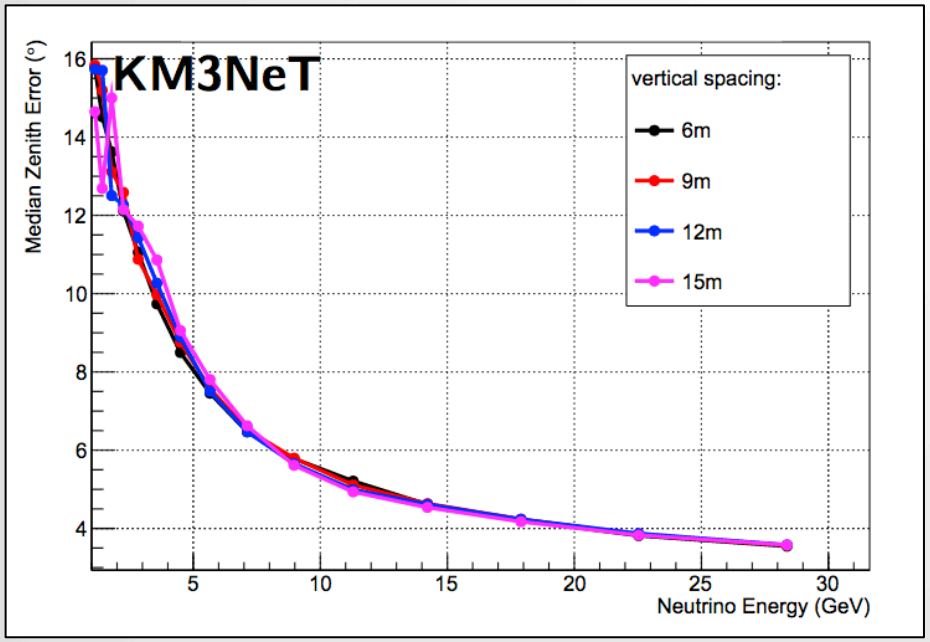
$E_{resol} = 25\%$ $\theta_{resol}=(m_p/E)^{1/2}$



- Measure neutrino and direction energy
- Search for oscillations patterns from matter effects
- Requires large statistics and good energy and direction resolutions

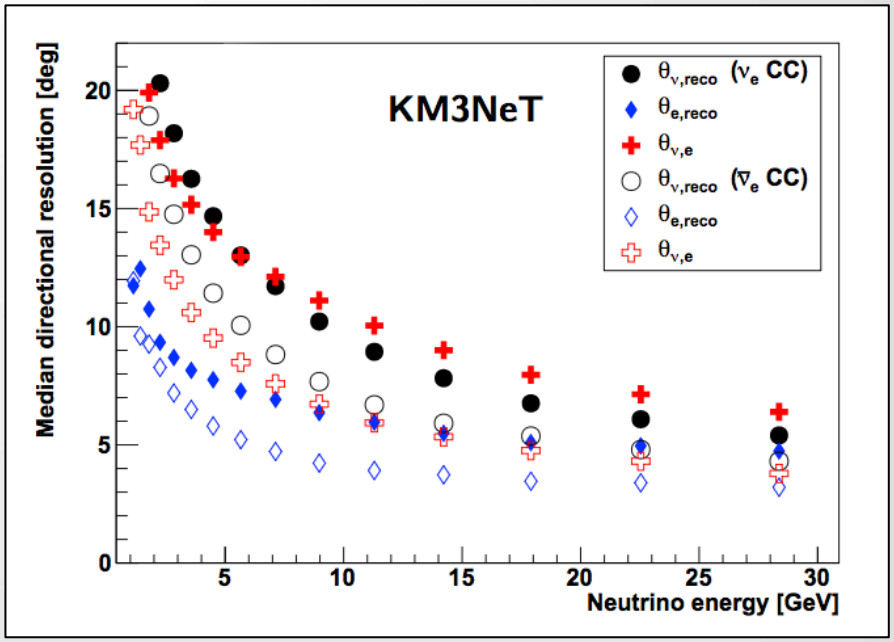
Performance for ORCA: Angular resolution

Track-like: ν_μ CC events



Median zenith angle error for track-like events.

Cascade-like: ν_e CC events

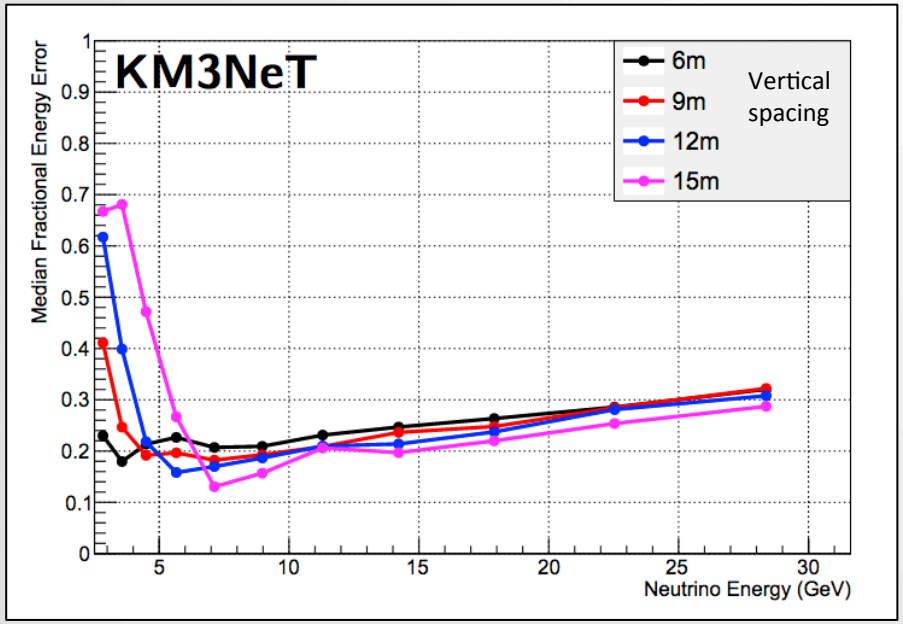


Median space angle for υ_e CC events.

- Resolution dominated by kinematics in both electron/muon channel.
- Better than 13° resolution above 5 GeV.

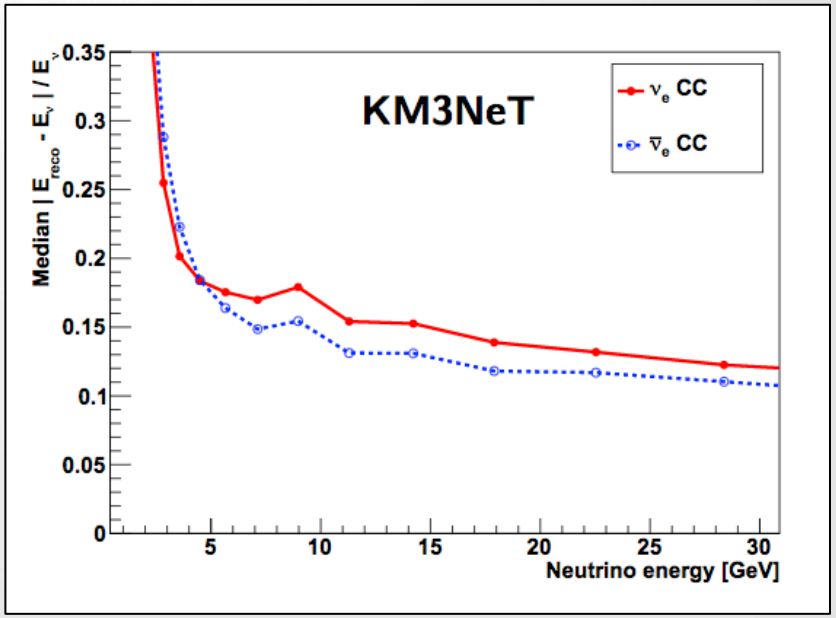
Performance for ORCA: Energy resolution

Track-like: ν_μ CC events



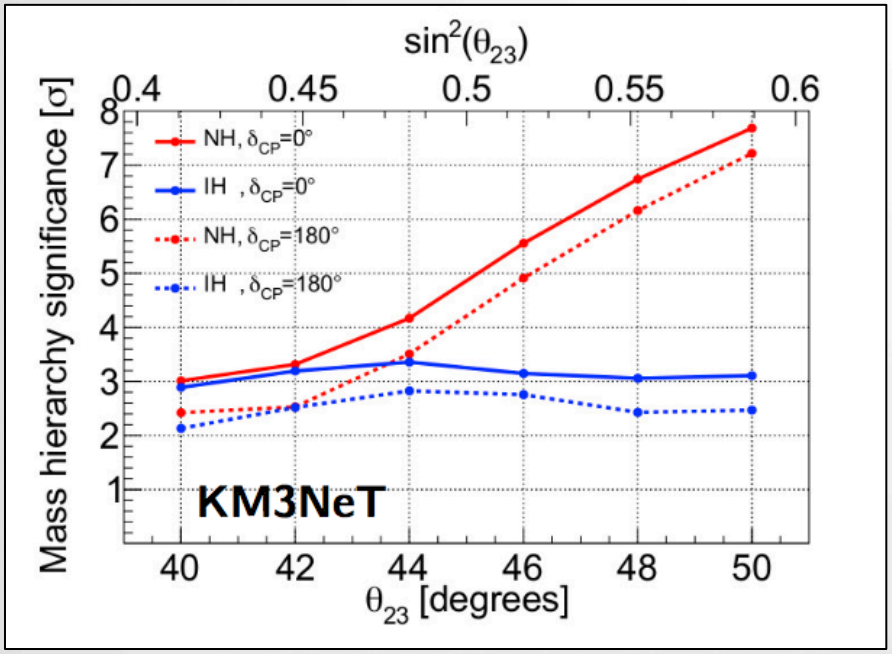
Median fractional energy error for track like events.

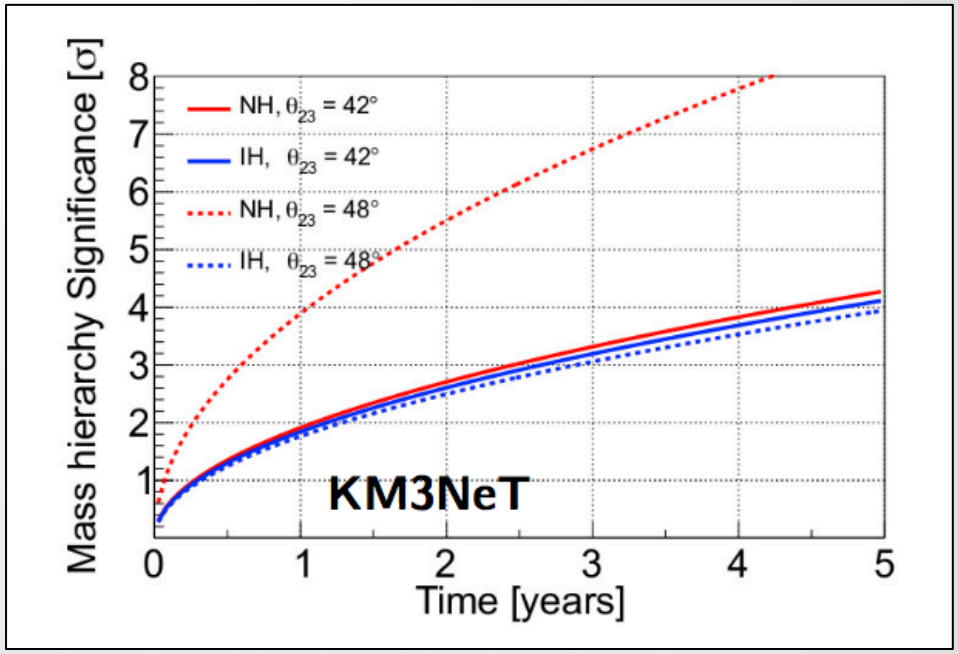
Cascade-like: ν_e CC events



Median fractional energy is better than 18% for events above 5 GeV.

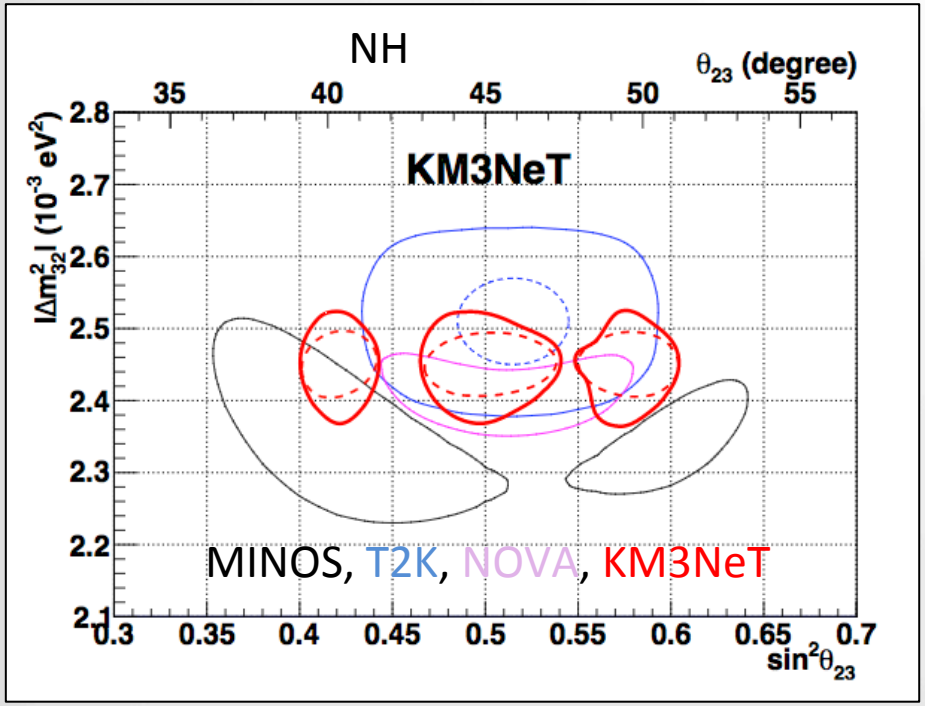
KM3NeT/ORCA: Sensitivity to NMH

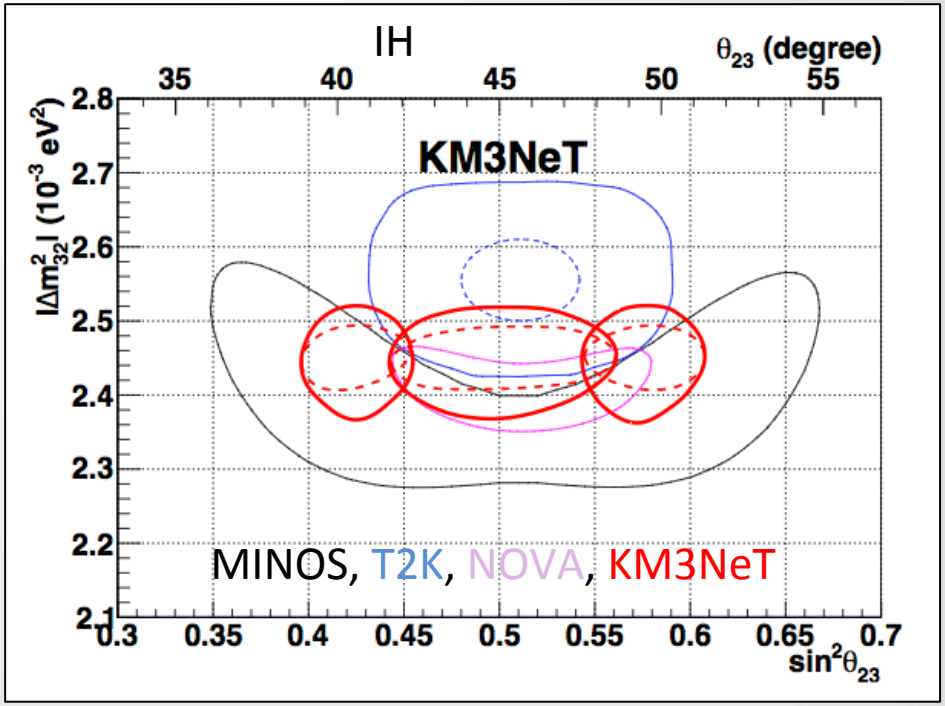




- ~3σ MH significance in 3 years of a complete KM3NeT/ORCA in most cases.
- If NH and θ_{23} in the second octant, significant improvement of sensitivity (>5σ!)
- In IH, small dependence on θ_{23}
- Best case scenario: 5σ in 1.5 years of complete ORCA!

KM3NeT/ORCA: Measurement of oscillation parameters





- Competitive with NOvA and T2K projected sensitivity in 2020
- KM3NeT/ORCA: red results (3 years obs. / Dashed: without E_υ scale)
- All contours at 1σ

Summary and conclusions

- Observation of HE neutrino flux discovered by IceCube expected in less than 1 year of a complete KM3NeT/ARCA detector!
- 3σ significance for galactic sources within 3-5 years
- ARCA angular resolution for track-like events of ~0.2° for energies above 10^5 GeV (<2° for cascades).
- NMH determination could be achieved at 3σ within 3 years from a complete KM3NeT/ORCA detector.
- Competitive measurement of oscillations parameters.
  - Letter of Intent for KM3NeT 2.0, J. Phys G: Nucl. Part. Phys. 43 084001 (also in arXiv:1601.07459)

- First DUs of KM3NeT have already been deployed.
  - First results obtained!

- Stay tuned!

Backup slides

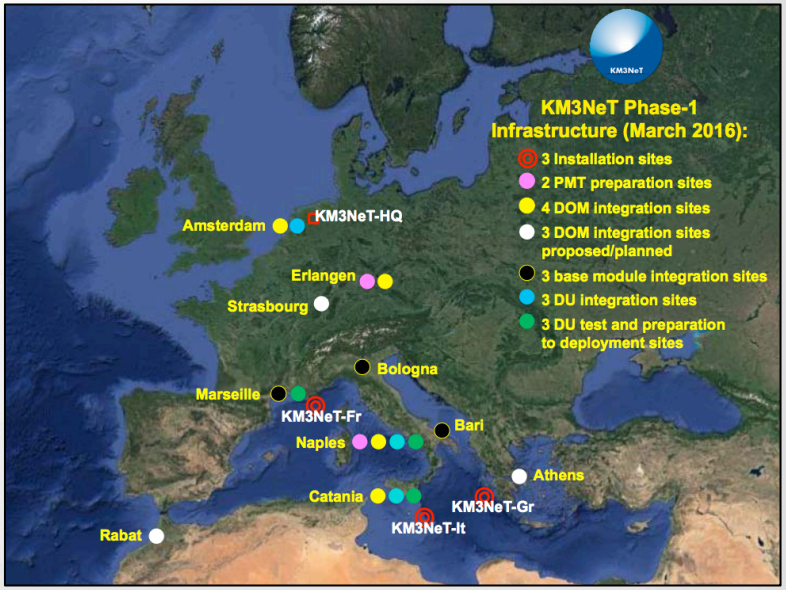
KM3NeT Construction phases

Phase 1: Proof of feasibility, first physics results

- Funded with 31 M€
- **31 DUs** to be deployed (2015-2017)
- KM3NeT-It offshore Capopassero @ 3500 m depth
  - 24 DUs – Volume of 0.1 km^3 (10 × Volume ANTARES)
  - Largest Neutrino Telescope in Northern Hemisphere!
  - First DU deployed in Dec 2015.
  - Second deployment in May 2016.
- KM3NeT-Fr offshore Toulon @ 2500 m depth (7 DUs)

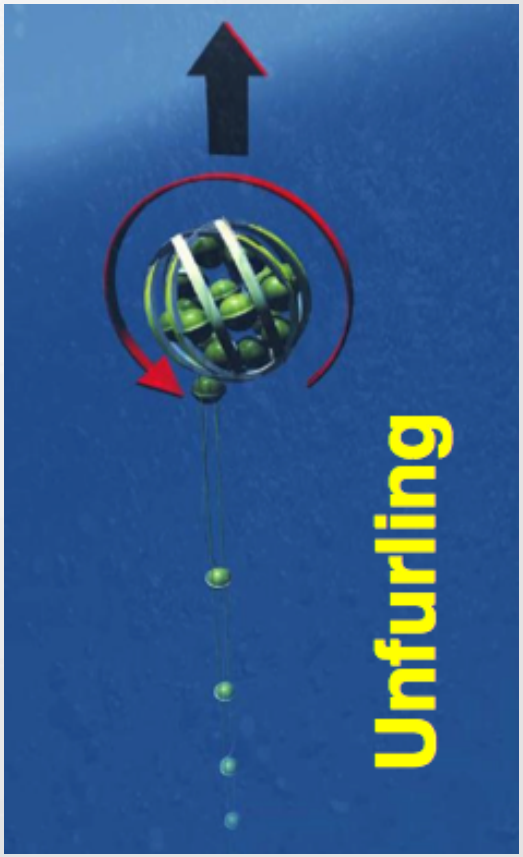
Phase 2: Detector completion

- **KM3NeT/ARCA:** High energy neutrino astronomy at the KM3NeT-It site (two blocks of 115 DUs each, 1 km^3 total)
- **KM3NeT/ORCA:** Neutrino mass hierarchy determination at the KM3NeT-Fr site.



KM3NeT Detector Production Sites

Deployment of DUs

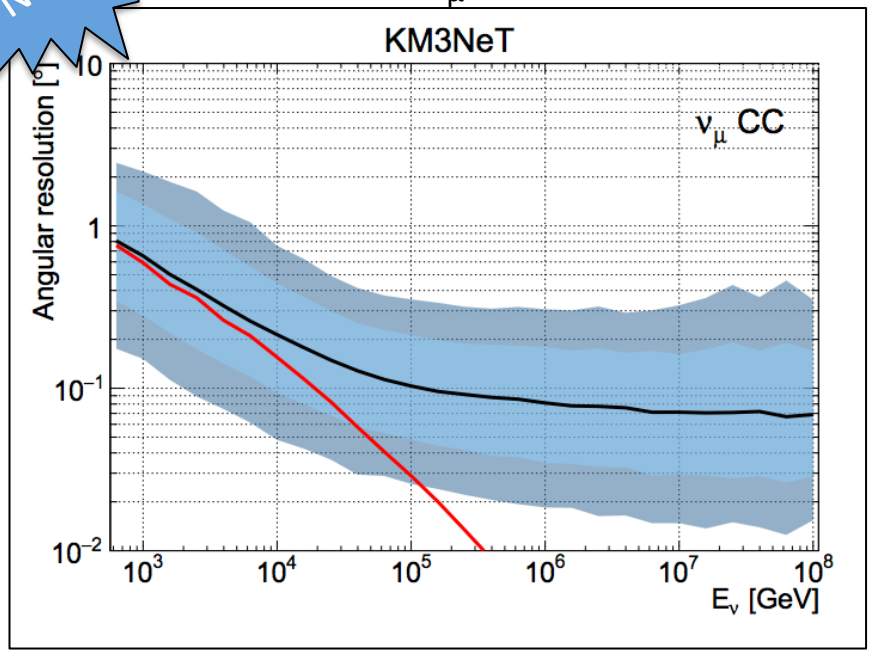


Video of last deployement in YouTube! https://www.youtube.com/watch?v=4Aynn5IfZ3I
(KM3NeT channel at ***KM3NeT**neutrino)*

Reconstruction performance for ARCA: Angular resolution

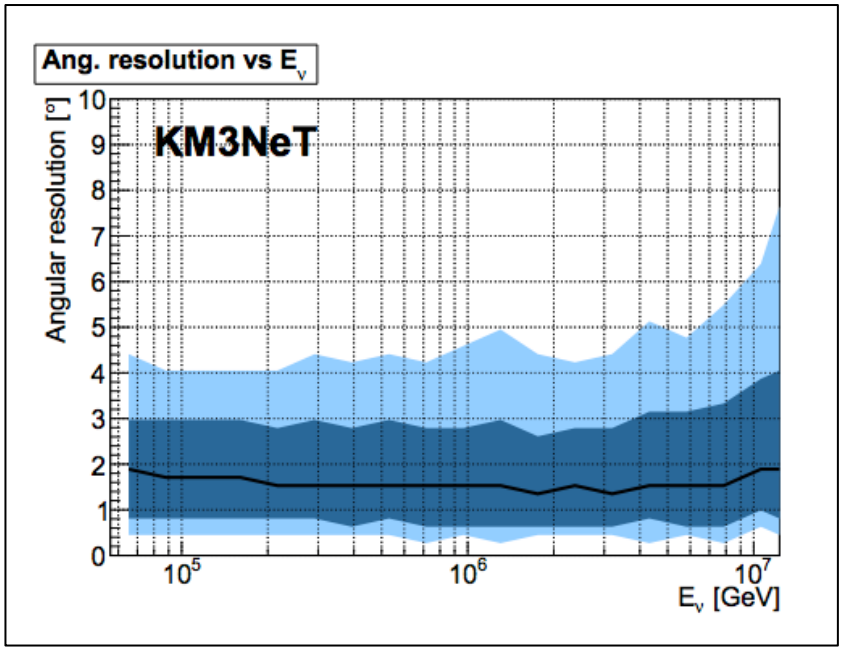
New!

Track-like: ν_μ CC events



Median angular resolution of <0.1° for energies above 10^5 GeV.

Cascade-like: ν_e CC events



Median angular resolution of <2° for energies above 10^5 GeV (z_{reco} < 200 m, r_{reco} < 500 m, ToT_{evt} > 12 μs)

Isotropic diffuse flux analysis

- Aim: Detection of the astrophysical flux observed by IceCube.
- Astrophysical flux assumed as isotropic, flavour-symmetric:

$$\Phi(E_\nu) = 1.2\times10^{-8}\left(\frac{E_\nu}{GeV}\right)^{-2}\exp\left(-\frac{E_\nu}{3PeV}\right)GeV^{-1}cm^{-2}s^{-1}sr^{-1}$$

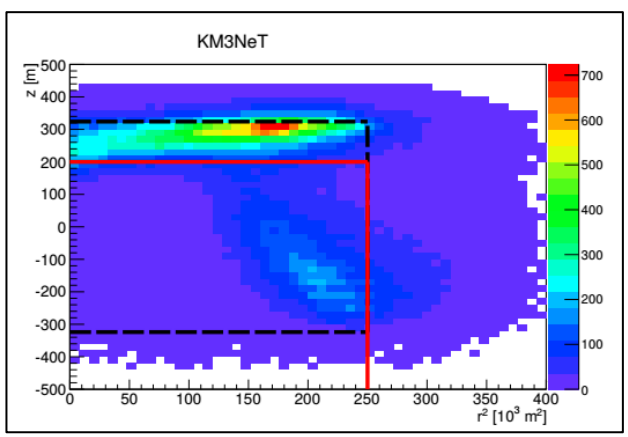
$$\Phi(E_\nu) = 4.11\times10^{-6}\left(\frac{E_\nu}{GeV}\right)^{-2.46}\exp\left(-\frac{E_\nu}{3PeV}\right)GeV^{-1}cm^{-2}s^{-1}sr^{-1}$$

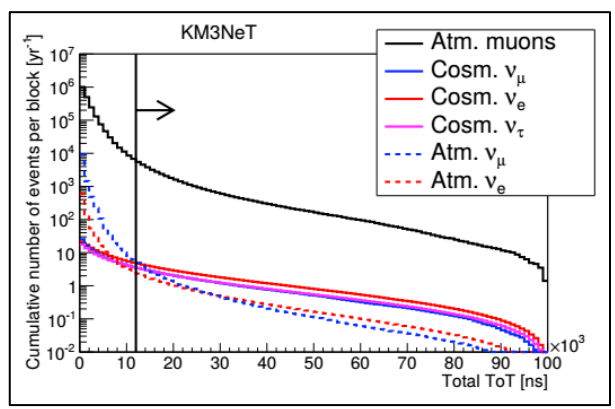
Event selection for cascade-like events:

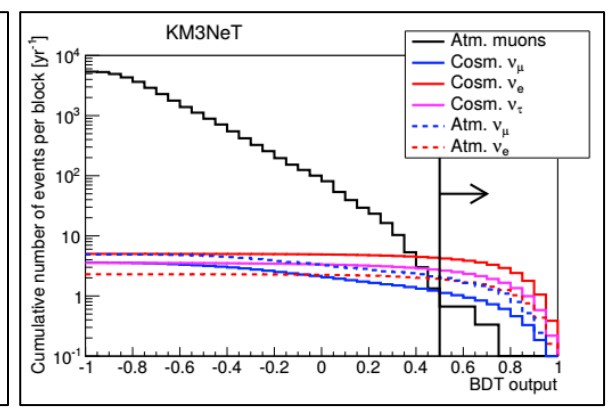
- Cut on reconstructed vertex
- Cut on cumulative ToT
- BDT training

Event selection for track-like events:

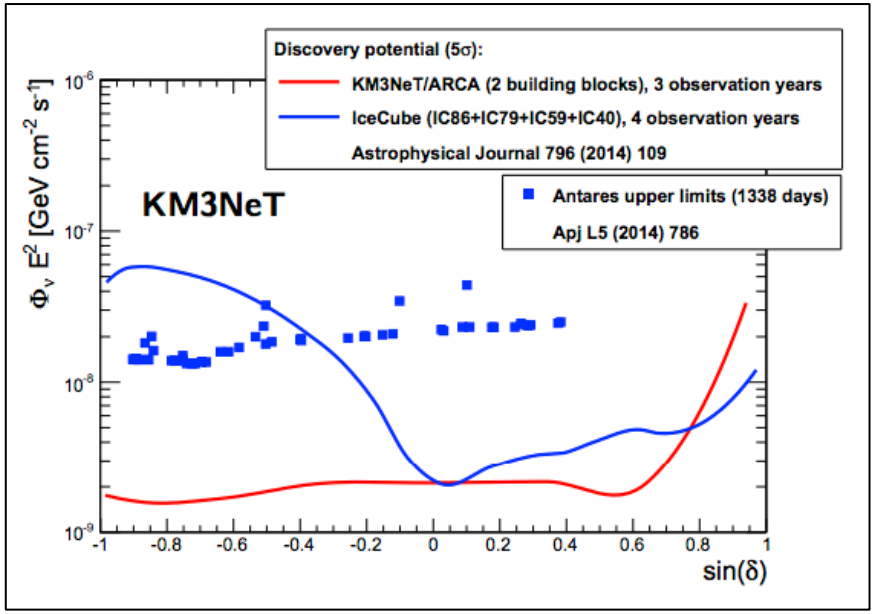
- $\Theta_{rec} > 80º$
- Cut on track-reconstruction quality (Λ>-5.8, N_{hit} >591)



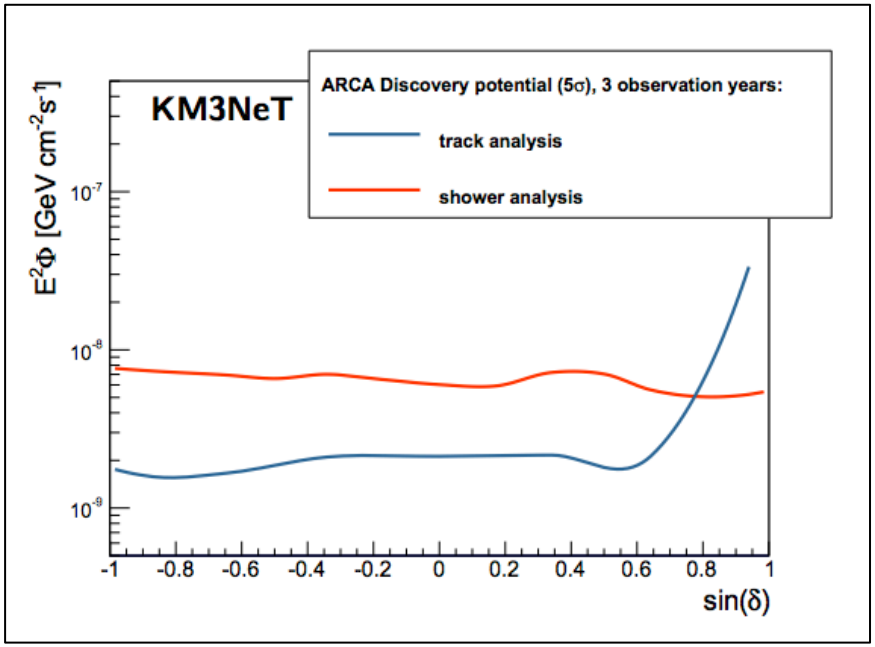




Point and extended source search analyses: E^{-2} sources



Discovery flux after 3 years of 2 blocks of KM3NeT/ARCA only using track-like events.



Discovery flux of the cascade and track channels of KM3NeT/ARCA after 3 observation years.

Event selection for track channel

Same as for galactic sources, but no use of BDTs.

Event selection for cascade channel

- Background suppresion via cuts on reconstructed vertex, cumulative ToT and muon-track quality parameter Λ
- Use of BDTs .