KM3NeT

opening a new window on our Universe

XVIII International Workshop on Neutrino Telescopes

18-22 March 2019

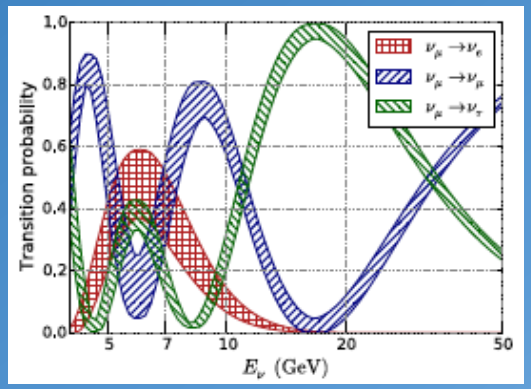
Venice, Italy

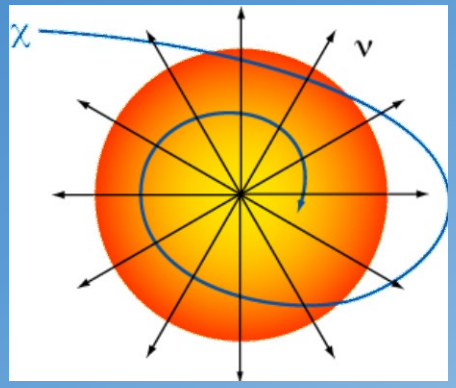
Mauro Taiuti on behalf of the **KM3NeT** collaboration

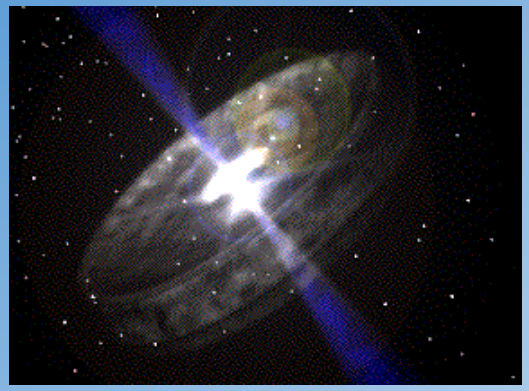
Outline

- Physics Motivations
- The Detectors
- The Performances
- Conclusions

Motivations & Objectives







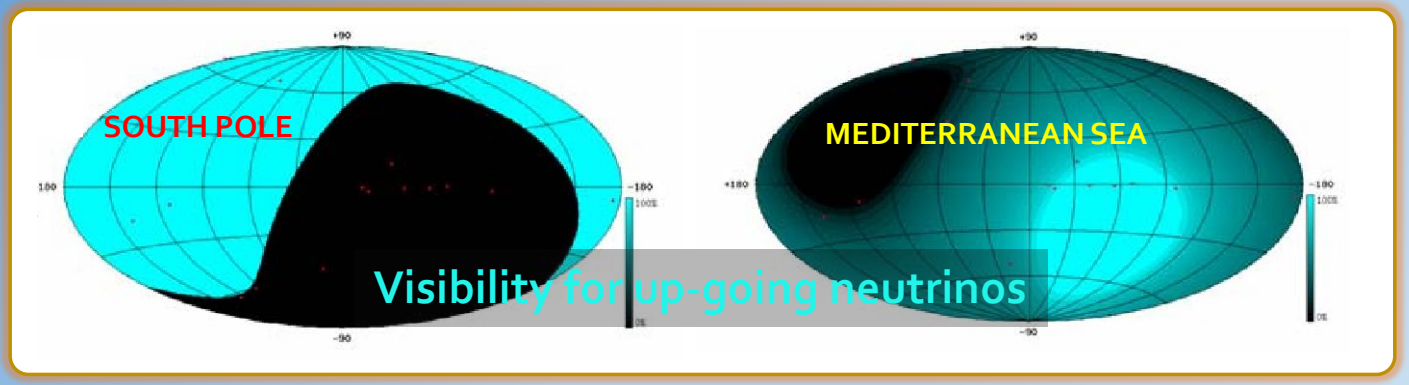
Low Energy	Medium Energy	High Energy
MeV < E_ν < 100 GeV	10 GeV < E_ν < 1 TeV	E_ν > 1 TeV
ν Oscillations Supernovae	Dark matter Monopoles, Nuclearites	Cosmic ν Origin and production mechanism of HE CR

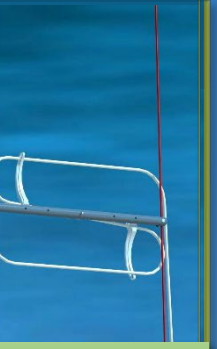
KM3NeT- ORCA ⟵ ⟶ KM3NeT- ARCA

+ oceanography, biology, seismology,…

Motivations & Objectives

- The **IceCube** discovery of HE cosmic neutrinos enforces the physics case of a km^3 neutrino telescope in the Mediterranean sea that surveys a large fraction of the sky including most of the galactic plane and the Galactic Centre
- Galactic versus extra-galactic contribution in **IceCube** data
  - quasi isotropic dominant component at high energy (E>100TeV) suggest extragalactic origin
  - some hints for a galactic contribution at lower energy, but can be probed only marginally with **IceCube** and **Antares**
- A much better angular resolution is achieved in deep sea w.r.t to ice





Astroparticle Research with Cosmics In the Abyss

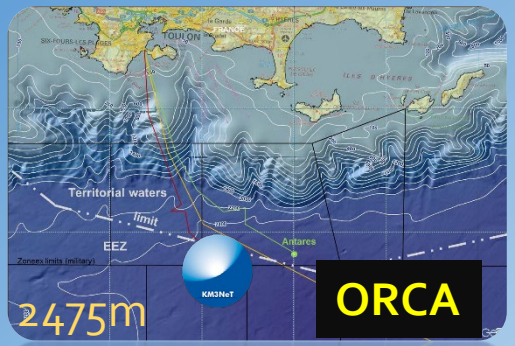
Oscillation Research with Cosmics In the Abyss

Motivations & Objectives

- **KM3NeT** is the neutrino research infrastructure in the deep Mediterranean Sea
  - discover and observe high neutrino sources in the Universe

    ARCA (off shore Capo Passero, It @ 3500 m depth)
  - determine neutrino mass hierarchy

    ORCA (off shore Toulon, Fr @2500 m depth)

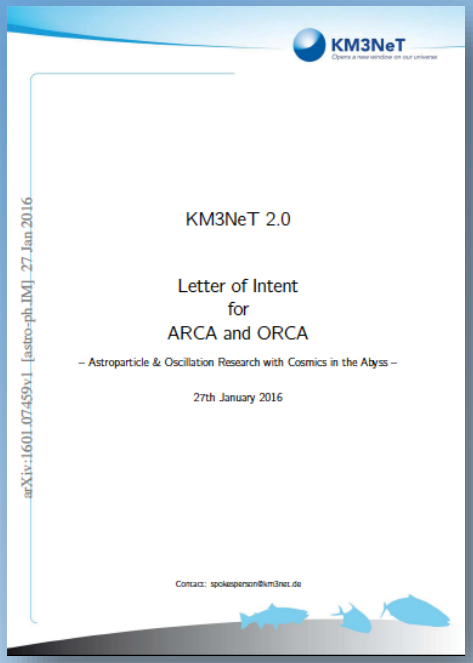


- Same collaboration, same technology, two installation sites

The Roadmap

KM3NeT selected for the 2016 ESFRI Roadmap

10 March 2016 – Today, at its launch event at the Royal Netherlands Academy of Arts and Sciences in Amsterdam, the European Strategy Forum for Research Infrastructures (ESFRI) announced that KM3NeT 2.0 is selected for the 2016 ESFRI Roadmap for Research Infrastructures. The ESFRI Roadmap identifies new Research Infrastructures of pan-European interest corresponding to the long-term needs of the European research communities. Its mission is to ensure that scientists in



- LoI: *J. Phys. G*, **43** (2016) 084001
- H2020: funds to prepare the ERIC
- Since 2016 **KM3NeT** is back in the ESFRI roadmap
- Since 2018 **KM3NeT** is in the APPEC roadmap
- The process to build the **KM3NeT** ERIC is in progress

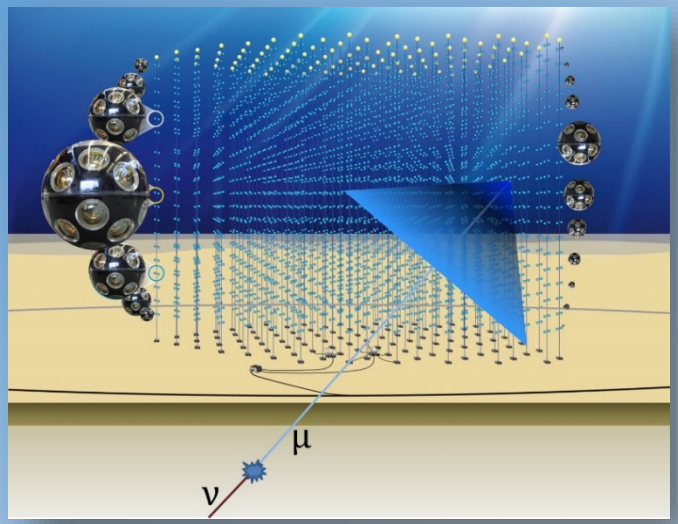
The **KM3NeT** Collaboration

- 15 Countries
- 55 Institutes
- >240 Scientists

- Number of Institutes and Scientists constantly increasing

The KM3NeT Telescope Design

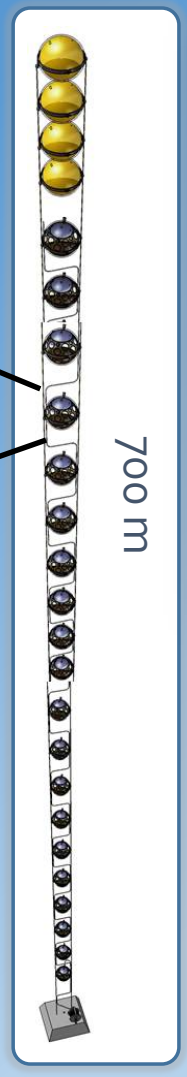
- Detection principle Optical Cherenkov radiation
  - 6 order of magnitude in energy (GeV-PeV)
  - All flavour detection
- A 3D array built with a modular design
- Optical sensor: multi-PMT (DOM)
- Detection units (DU)
  - vertical slender strings host 18 DOMs
- Building blocks of 115 DUs each
- Power and data distributed by a single backbone cable with breakouts at DOMs
- Sea network of submarine cables and Junction Boxes connected to shore via a main e/o cable
- All data to shore



	ARCA	ORCA
Location	Italy	France
DU distance	90 m	23 m
DOM spacing	36 m	9 m
Instrumented mass	2*500 Mton	8 Mton

The Detection Unit

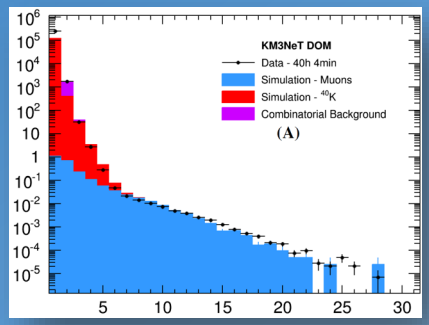
- 18 DOM integrated on vertical slender strings supported by two parallel Dynema ropes



- Strings arranged on the LOM, mounted on the anchor and ready for deployment

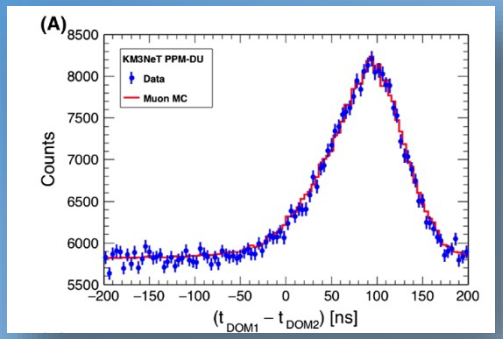
From Validation to Construction

Prototype DOM deployed at Antares site April 2013



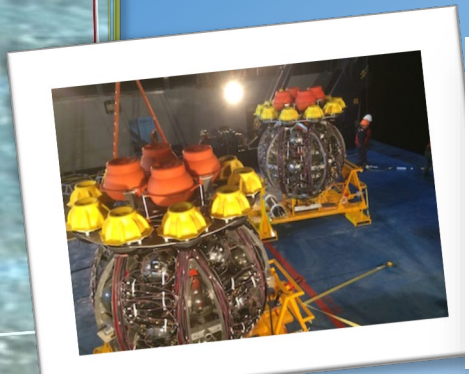
Test of photon counting capabilities and directional sensitivity of DOM
Eur. Phys. J. C (2014) 74:3056

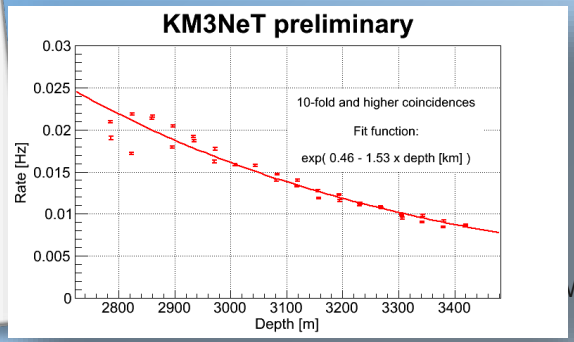
Prototype DU (three DOMs) deployed in Capo Passero May 2014



Test of DU structure functionality
Test of intra-DOM and inter-DOM calibration - *Eur. Phys. J. C (2016) 76:54*

First ARCA DU deployed in Capo Passero December 2015





Muon flux dependence on depth
DU calibration
Trigger implementation
Track reconstruction e MC comparison
…

A Phased Approach

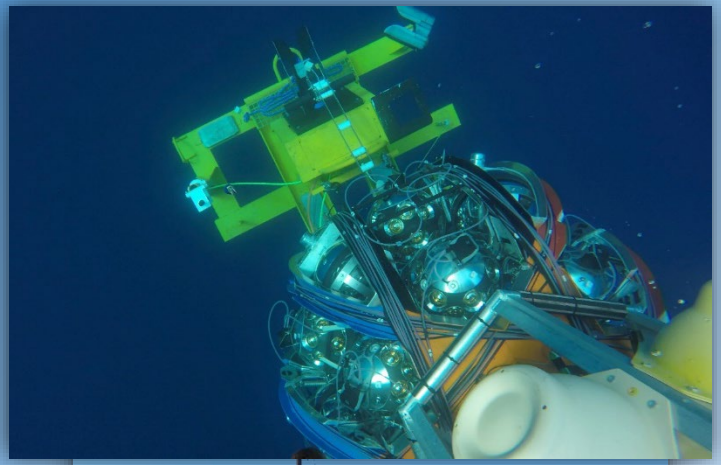
PHASE	BLOCKS	PRIMARY DELIVERABLES	FUNDS
1	0.2	Proof of feasibility and first science results 24 ARCA + 6 ORCA strings	Fully funded
2	2+1	All flavor neutrino physics and astronomy 2 x 115 ARCA strings 1 x 115 ORCA strings	Funding in progress
3	6	Neutrino astronomy including Galactic sources	Not yet

Phase 1 - ARCA

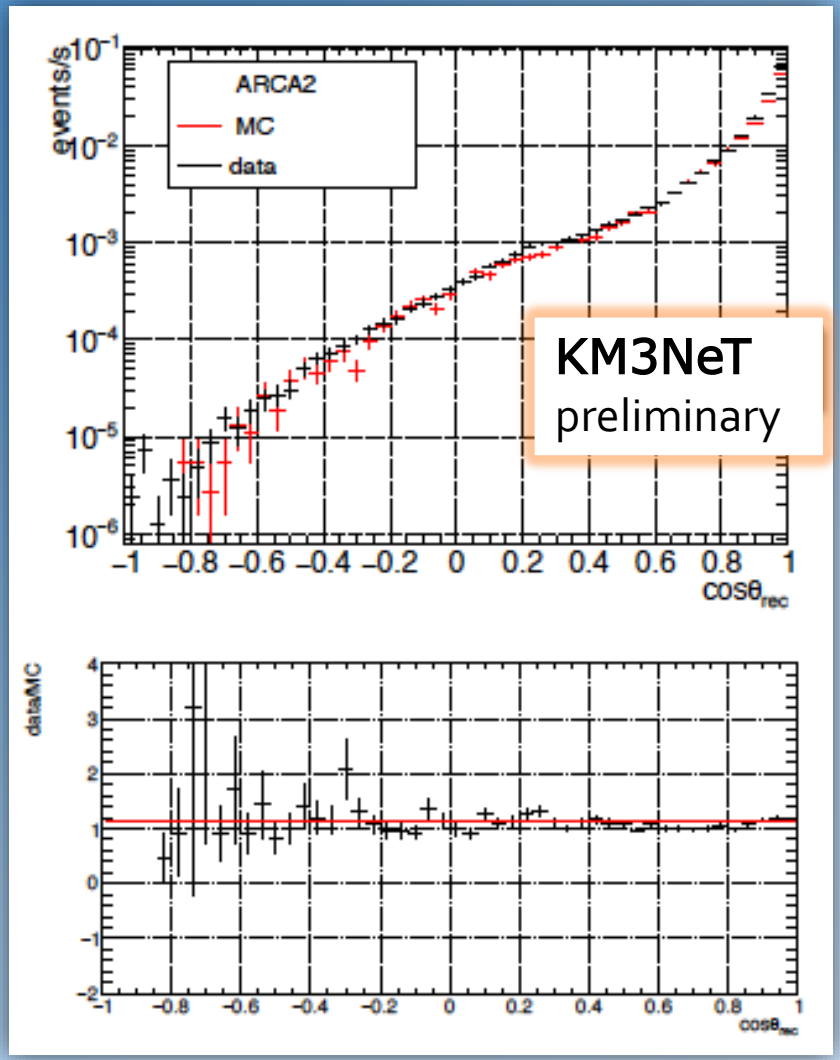
- ARCA-DU1 and ARCA-DU2
  - deployed December 2015 and May 2016 at Capo Passero, Sicily
  - worked till April 2017
  - ARCA-DU1 operativity resumed in January 2019
  - plenty of statistics
  - Data analysis of atmospheric muons shows excellent agreement between data and MonteCarlo

Phase 1 - ORCA

- First ORCA DU successfully deployed and connected in September 22, 2017
- Replacement of the cable during two different sea campaigns in October 2018 (12-16 and 22-26)
- Re-installation of the ORCA DU in Feb 14-17, 2019
- 5 additional DUs ready for deployment in early April

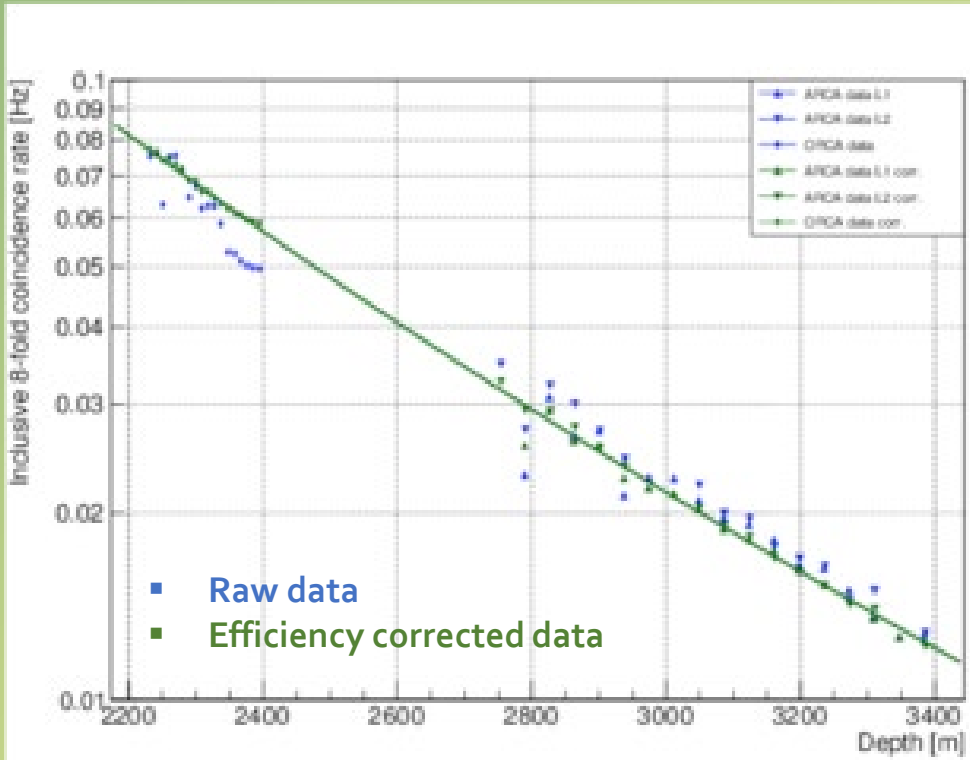


Phase 1 - ARCA


events/s
ARCA2
MC
data
KM3NeT
preliminary
cosθrec
data/MC
cosθrec

ARCA + ORCA Muon Depth Dependence

- Joint analysis shows the muon flux attenuation over more than 1 km length

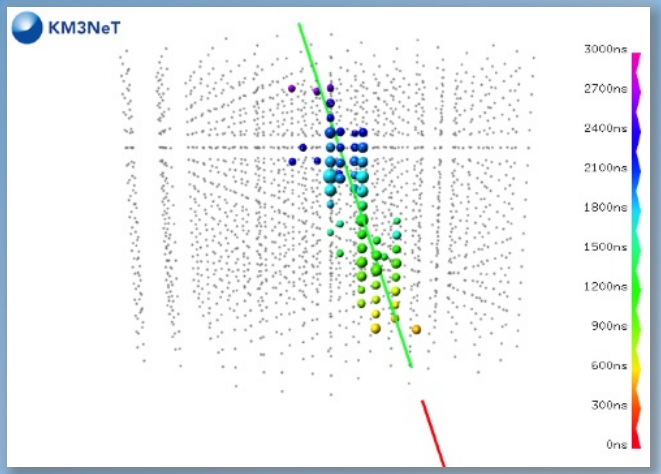


Phase 1 - Summary

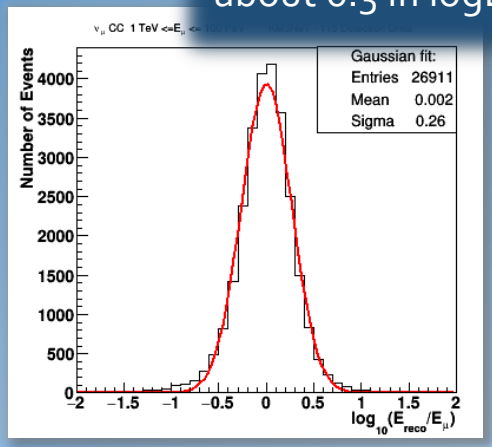
- Several lessons learned
- Quality of DUs highly improved
- Quality Assurance generally improved
- The detectors performances are well under control
- We are confidently proceeding with the integration of the next DUs
- We have the economical and manpower capability to integrate and deploy 119 DUs in two years (1/3 of the full detector)

Event Topologies and Detector Response

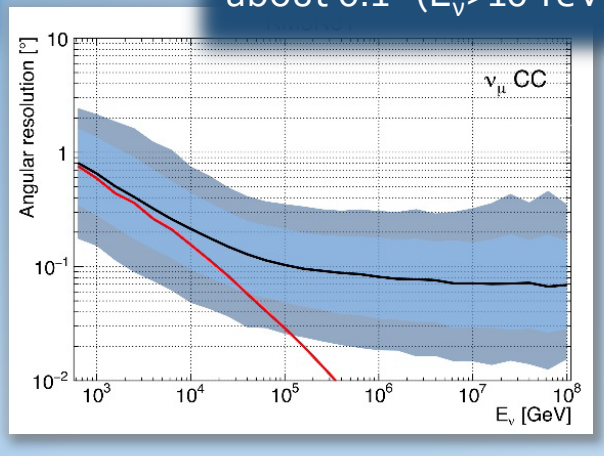
- ν_μ are the golden channel for neutrino astronomy
- Deep sea water properties, i.e. long scattering length allow to achieve very good angular resolution



Energy resolution about 0.3 in logE_μ

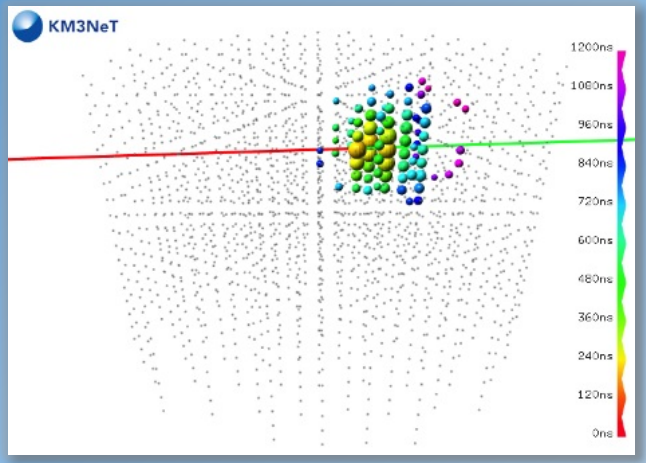


Angular resolution about 0.1° (E_ν>10 TeV)

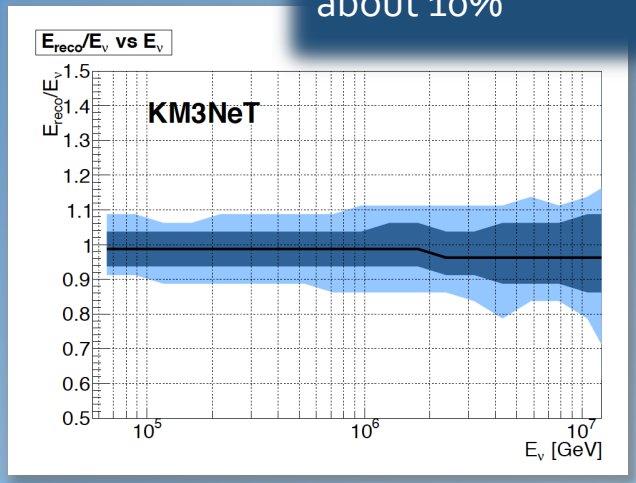


Event Topologies and Detector Response

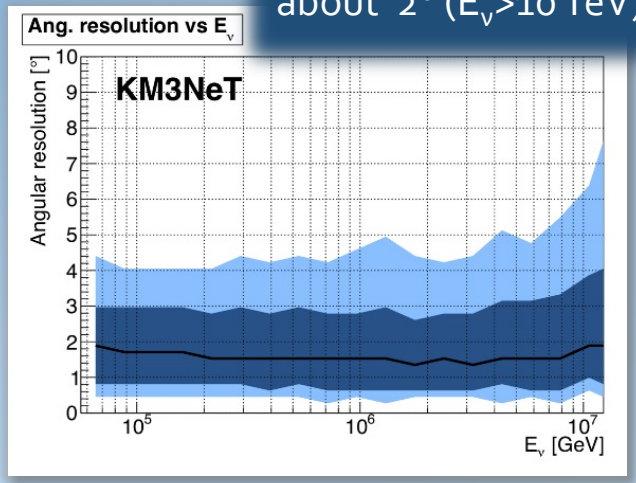
- Contained shower ν_e



Energy resolution about 10%



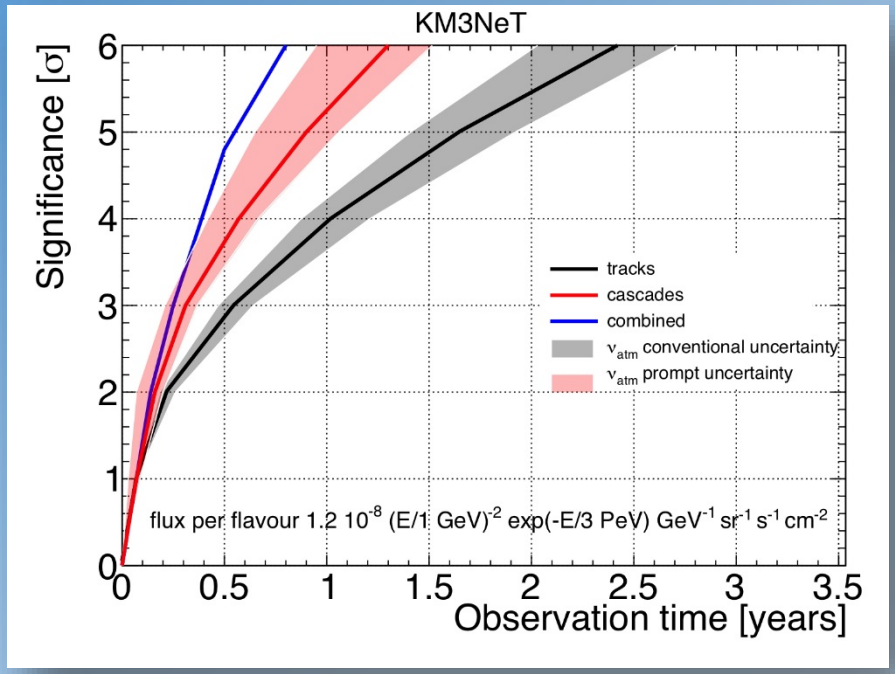
Angular resolution about 2° (E_ν>10 TeV)



ARCA Sensitivity to Diffuse Neutrino Flux

EVENT ANALYSIS

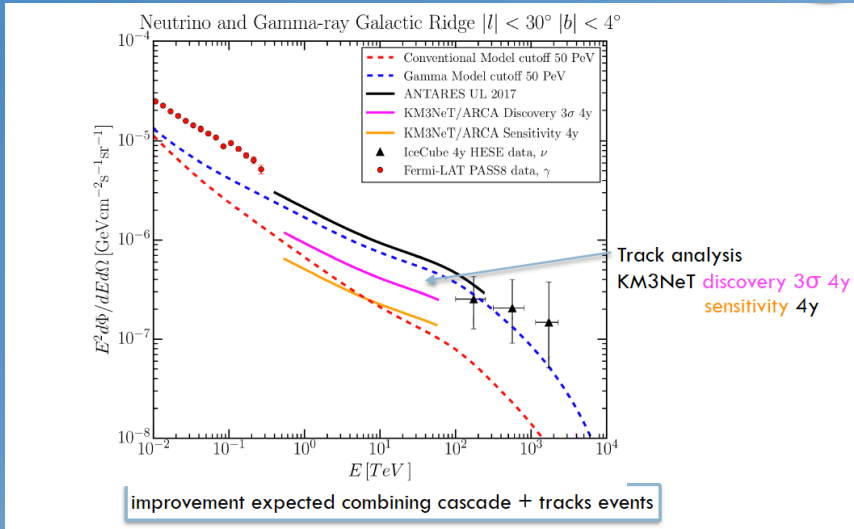
- **Track channel:** analysis for up-going events based on Max. likelihood
  - Pre-Cuts on θ_{zen} >80°, Λ (reconstruction quality parameter), N_{hit} (number of hits → parameter related to the muon energy)
- **Cascade channel**: contained events
  - **Vertex cut**: cut on position of reconstructed vertex (z<200 m .AND. r<500 m)
  - **Energy cut**: cut on the total ToT of the event (ToT>12 μs)

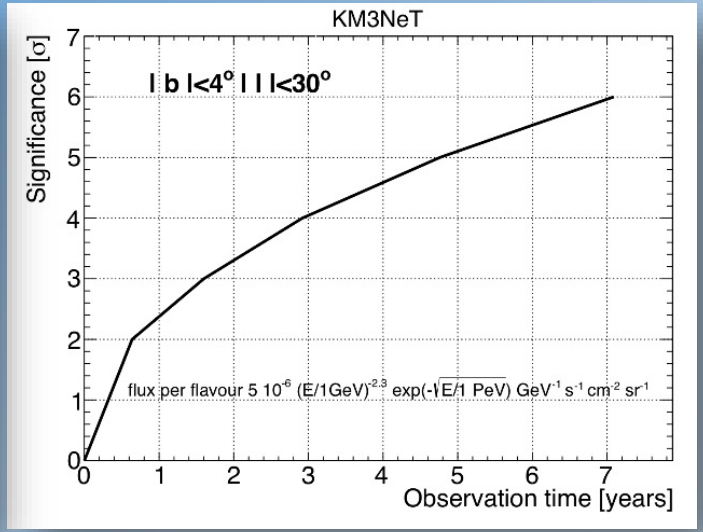


Discovery at 5σ significance in less than one year

Diffuse Flux from the Galactic Plane

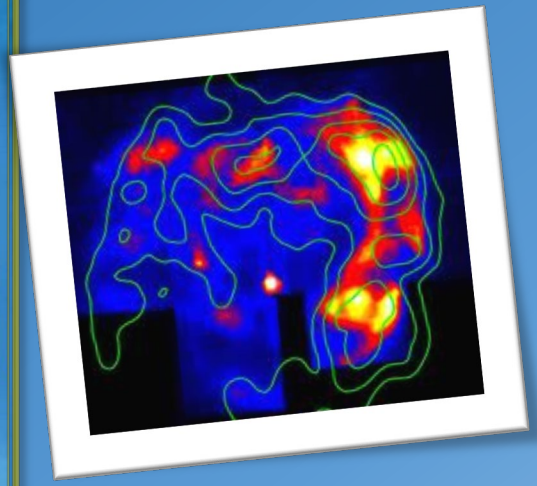
- **ARCA** sensitivity to a flux from a region of the Galactic Plane near the Galactic Center Neutrino flux estimate based on a radially-dependent cosmic-ray transport properties

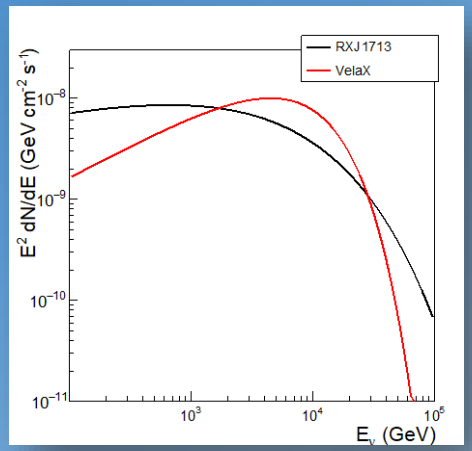


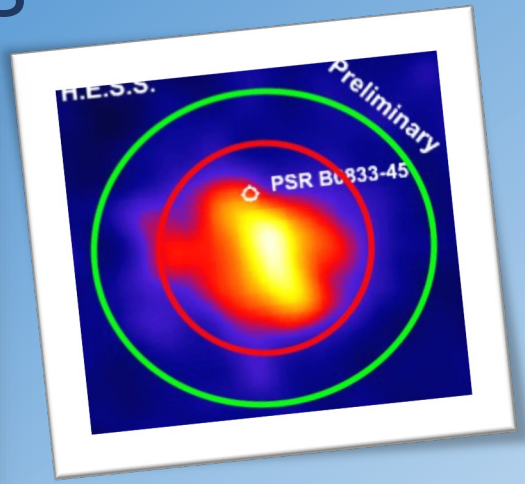


Discovery at 5σ significance in about 5 years

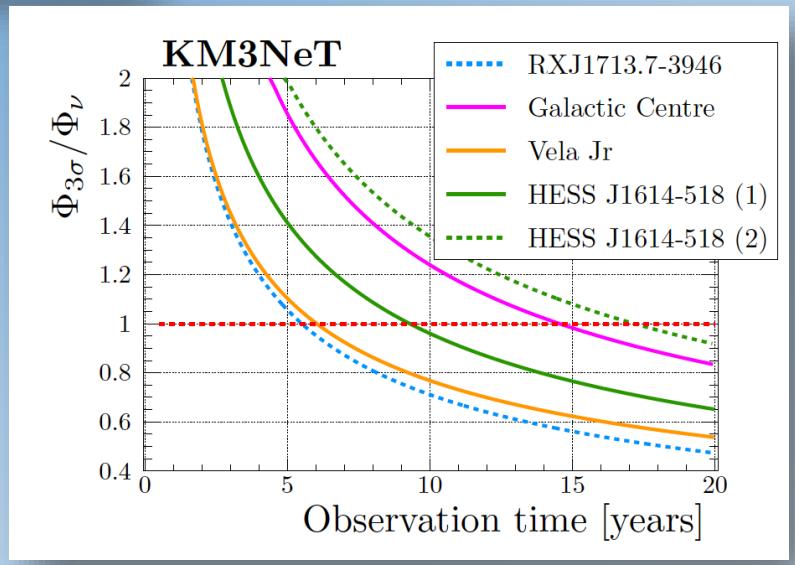
ARCA Sensitivity to Point-like Galactic Sources





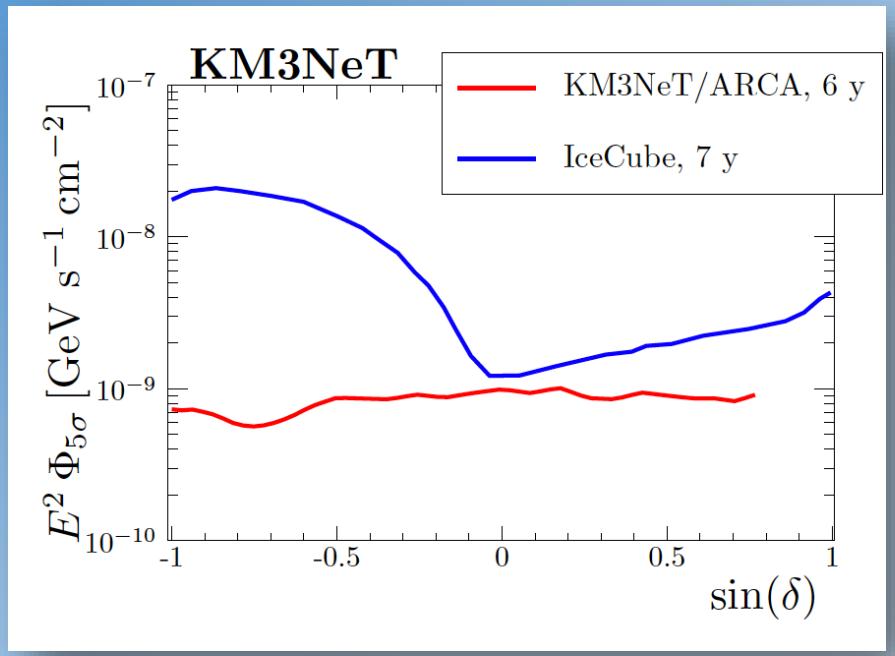


- HE gamma emission observed by HESS in SNRs
- Neutrino spectra predicted using gamma spectra
  - ¶ S.R. Kelner, *et al.*, PRD 74 (2006) 034018
  - § F.L. Villante and F. Vissani, PRD 78 (2008) 103007
- Hypotheses: 100% hadronic emission and transparent source

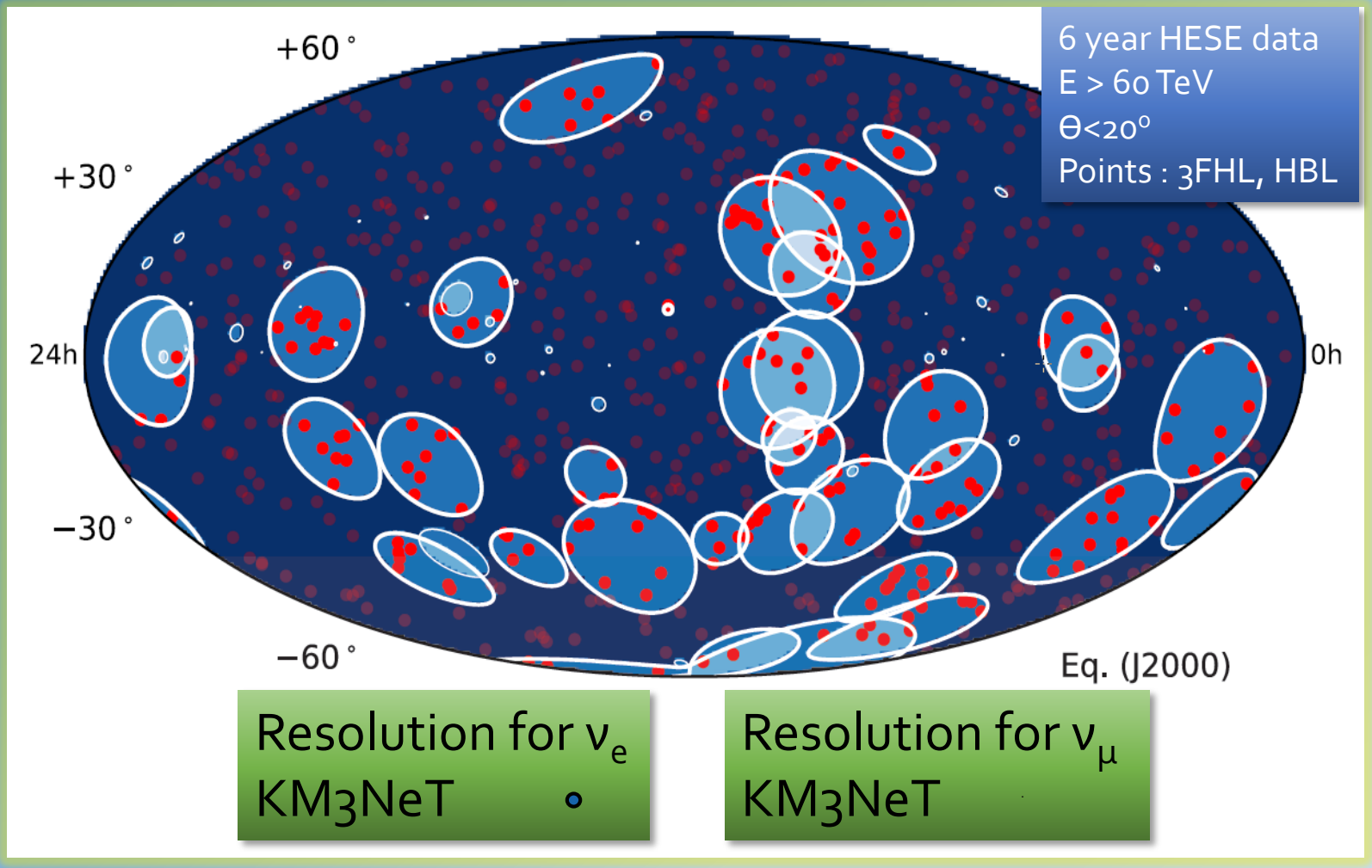


ARCA Sensitivity to Point-like Sources E^{-2} up-going ν_μ

- **ARCA** can survey almost the whole sky with a discovery potential @ 5σ about one order of magnitude better than **IceCube** for equivalent exposure



ARCA Angular Resolution



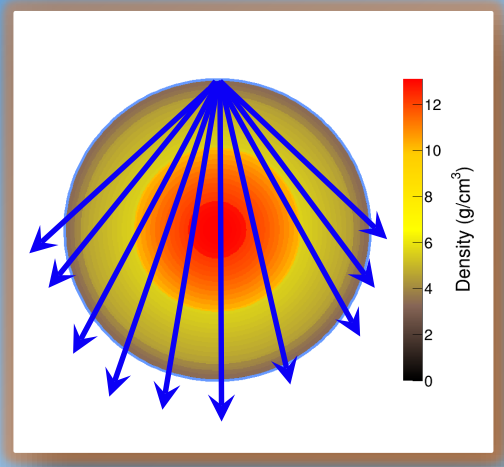
Neutrino Mass Hierarchy with ORCA

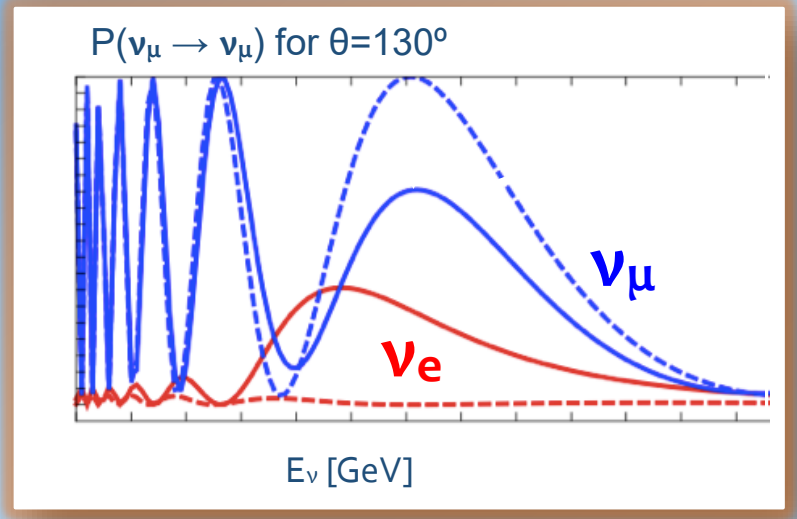
- A "*free beam*" of known composition (ν_e, ν_μ)
- Wide range of baselines and energies
- Oscillation pattern distorted by Earth matter effects

  maximum difference IH vs NH for resonance in

  Earth mantle: θ=130° (7645 km)

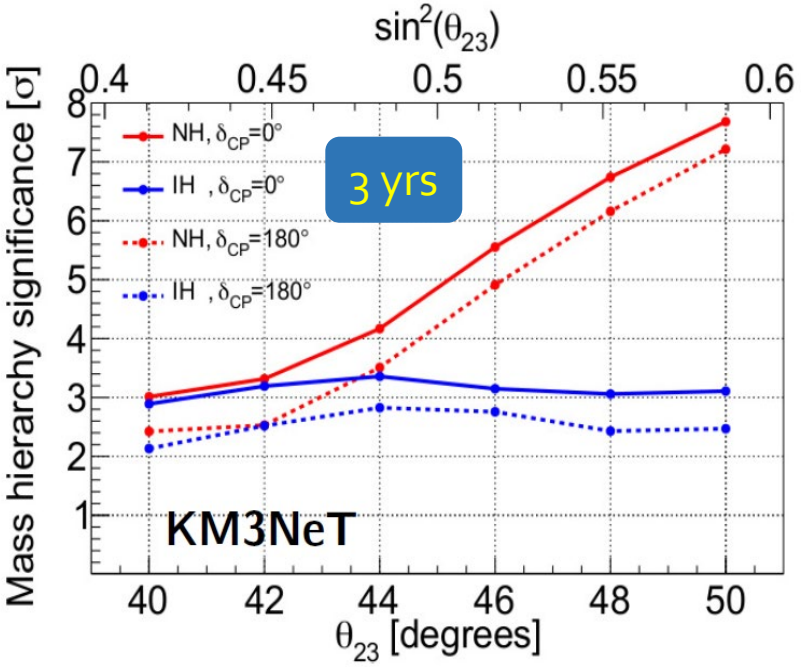
  and E_ν = 7 GeV

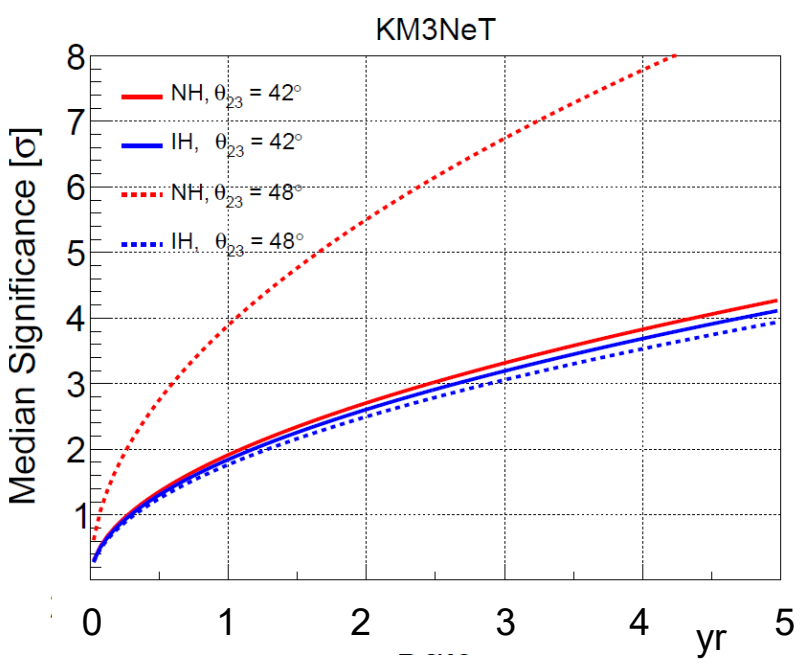




ORCA Sensitivity to Mass Hierarchy

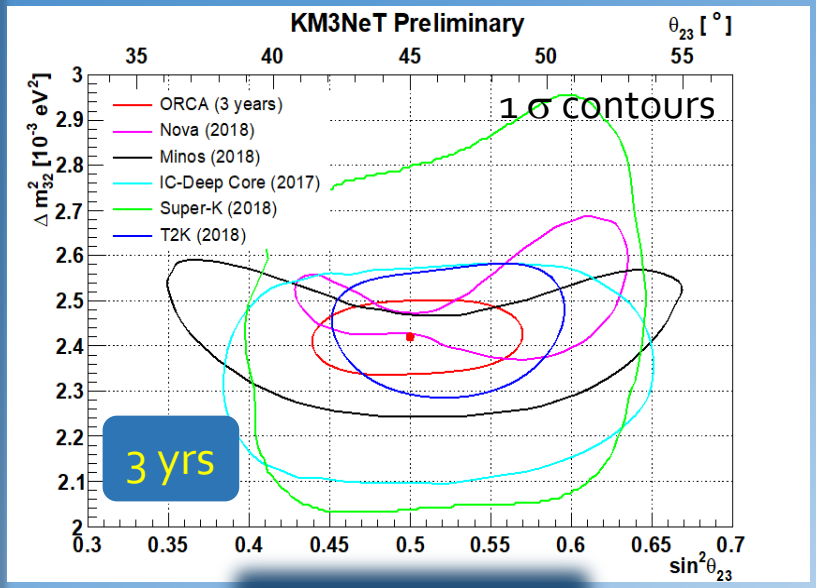
- After 3 years 3σ for most of the parameter space
- NH and 2-nd Octant of θ_{23} much better



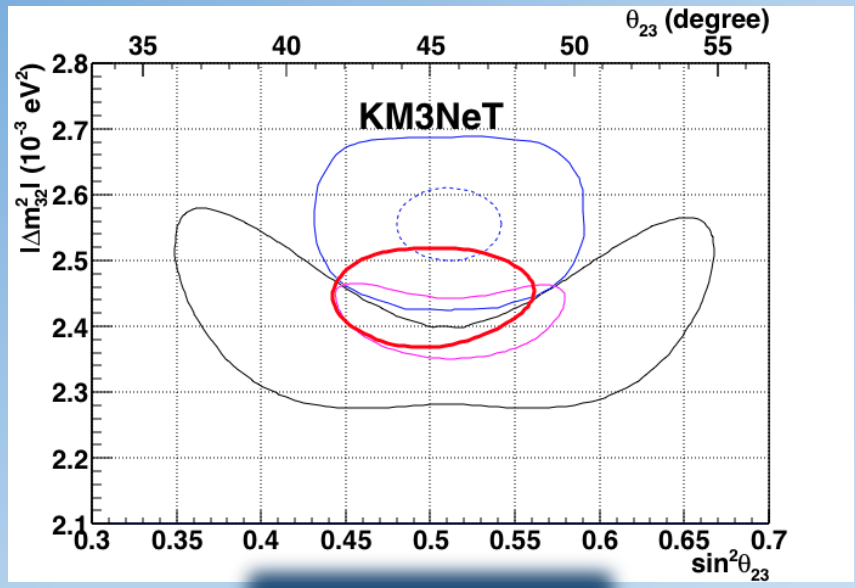


ORCA Measurement of Δm^2_{32} and $\sin^2\theta_{23}$

- Achieve 2-3% precision in Δm^2_{32} and 4-10% in $\sin^2\theta_{23}$
- Competitive with NOvA and T2K projected sensitivity in 2020
- T2K 7.8 10^{21} p.o.t.



Normal Hierarchy



Inverted Hierarchy

Additional **ORCA** Physics Topics

- Unitarity of PMNS matrix
- Exotic physics
  - sterile neutrino, non-standard interactions
- Dark Matter
- Earth tomography
- Low energy neutrino astronomy
  - Transient phenomena
- Supernovae monitoring
- Earth and Sea Science
- Neutrino beam from Protvino

Conclusions

- **Phase-1**
  - Technology is being validated
  - Good quality data - Analysis in progress
- **Phase-2**
  - Money are becoming available
  - Construction in progress
- **KM3NeT** is going to become a key infrastructure for neutrino astronomy in the next decade

Thank you!