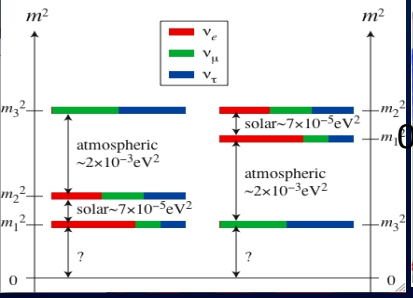
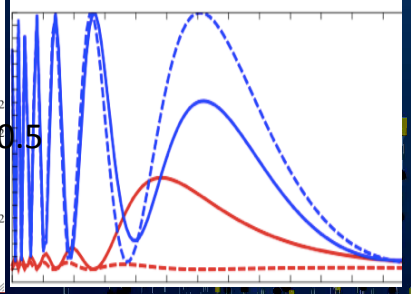
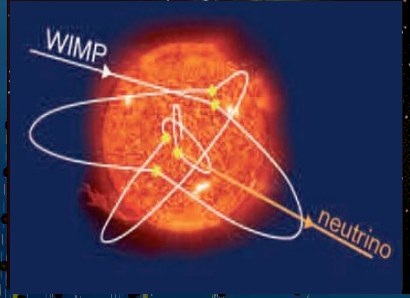






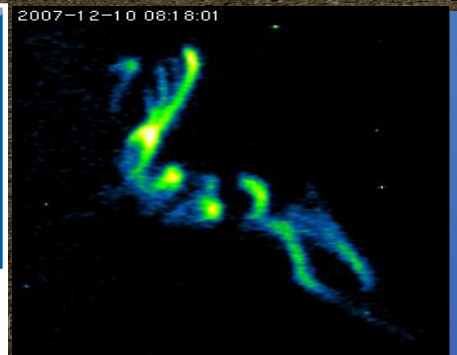
Status of KM3NeT/ORCA: Oscillation Research in the Abyss

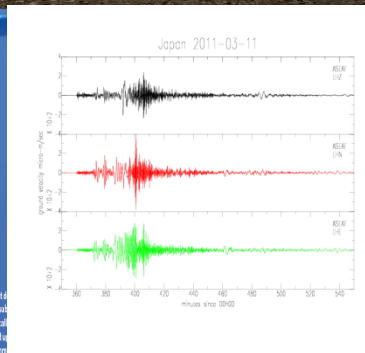
NNN2017, Warwick

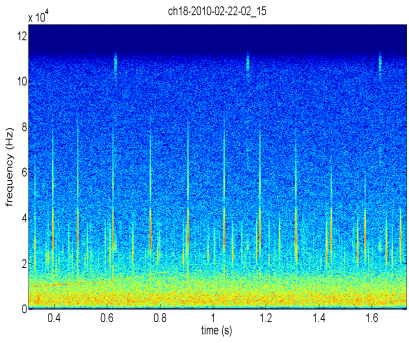
27/10/17

Paschal Coyle
Centre de Physique des Particules de Marseille

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM







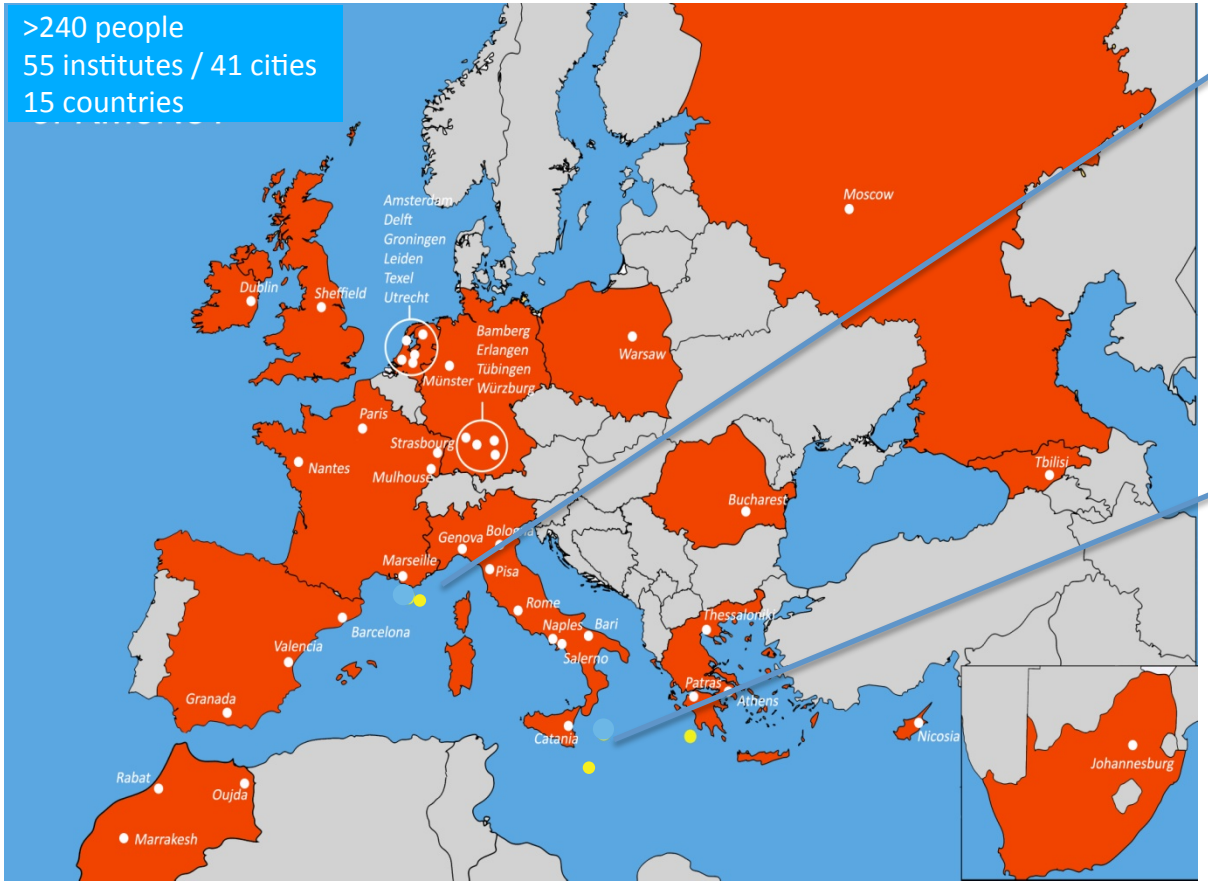
KM3NeT

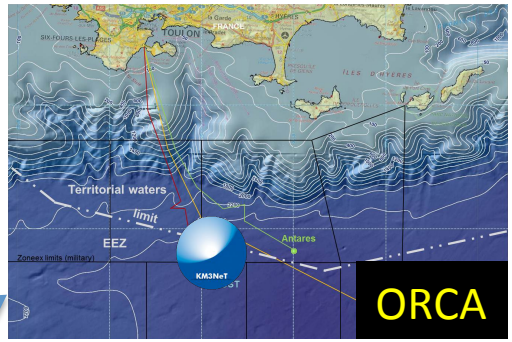
Multi-site, deep-sea infrastructure

Selected by ESFRI roadmap

Single collaboration, Single technology

>240 people
55 institutes / 41 cities
15 countries



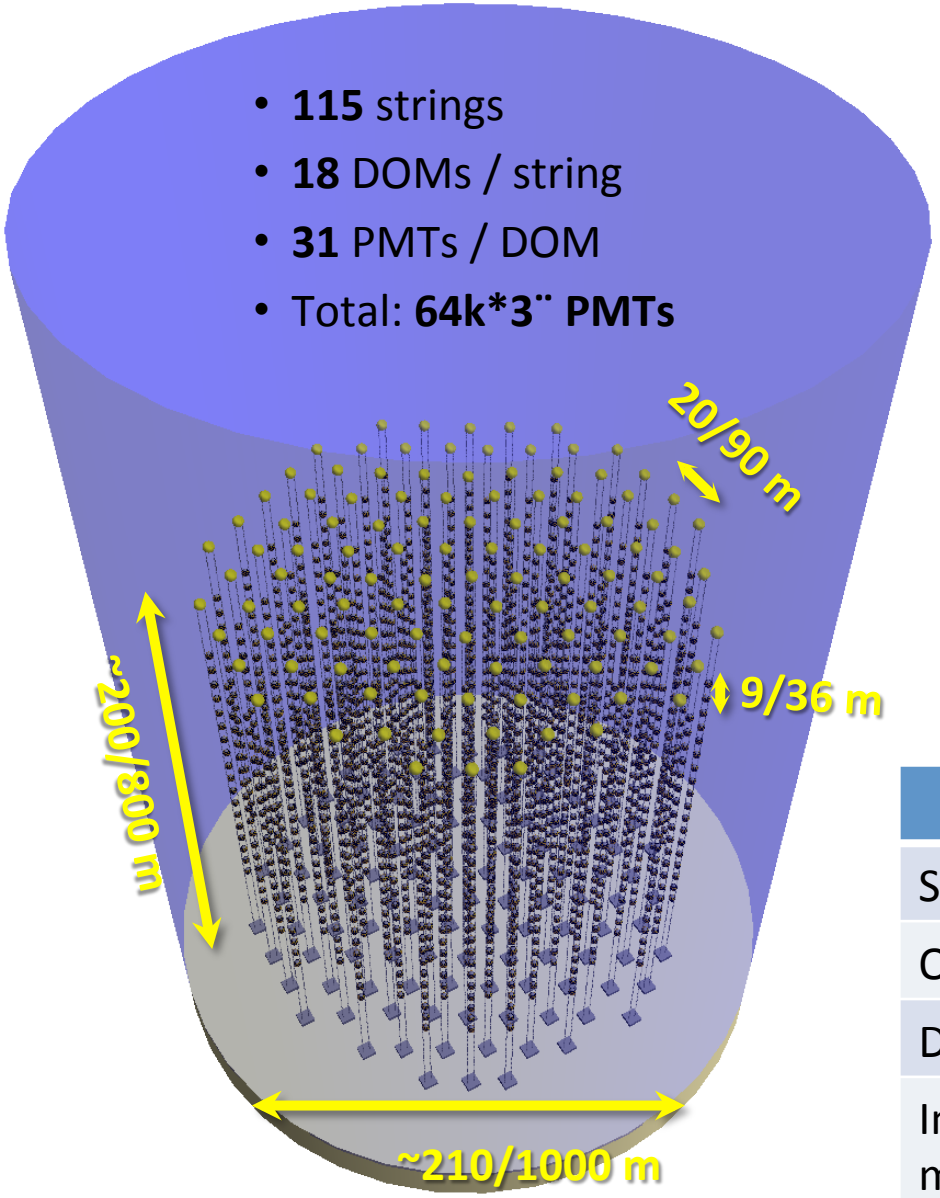


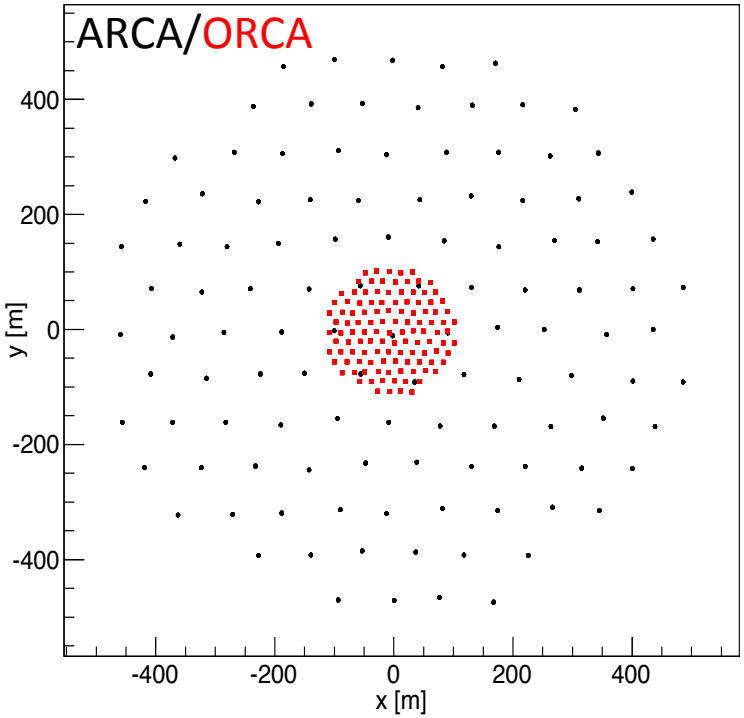
Oscillation **R**esearch
with **C**osmics In the **A**byss

Astroparticle **R**esearch
with **C**osmics In the **A**byss

Connection nodes of
european multidisciplinary seafloor & water column observatory
emso

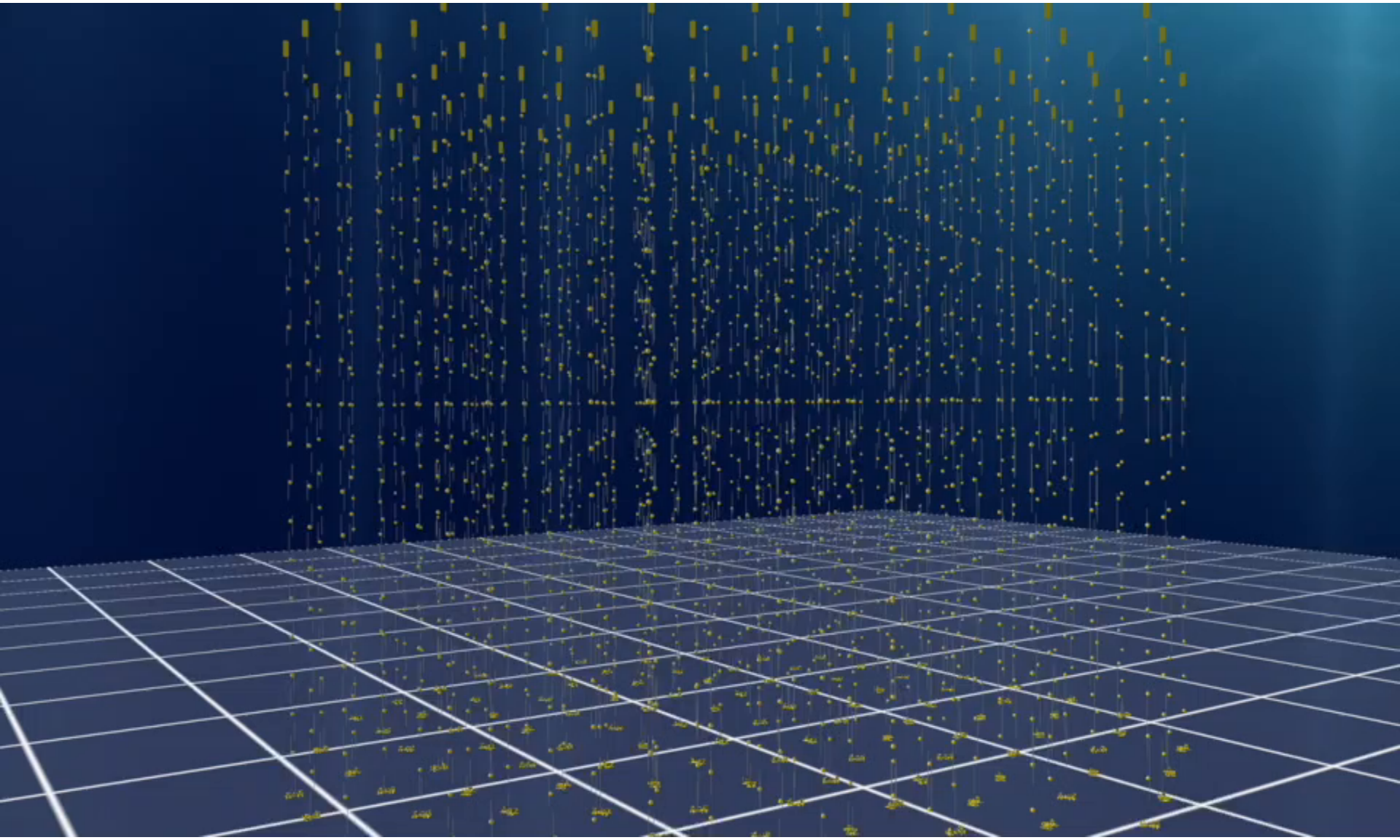
KM3NeT Building Block





	ORCA	ARCA
String spacing	23 m	90 m
OM spacing	9 m	36 m
Depth	2470 m	3500 m
Instrumented mass	8 Mton	0.6*2 Gton

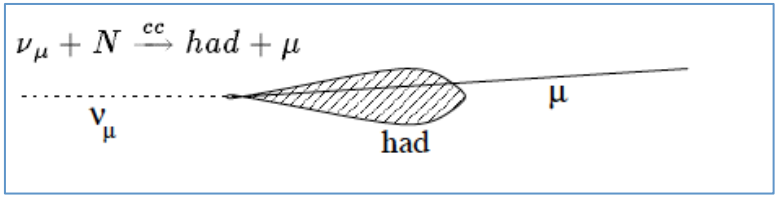
Principle of Detection



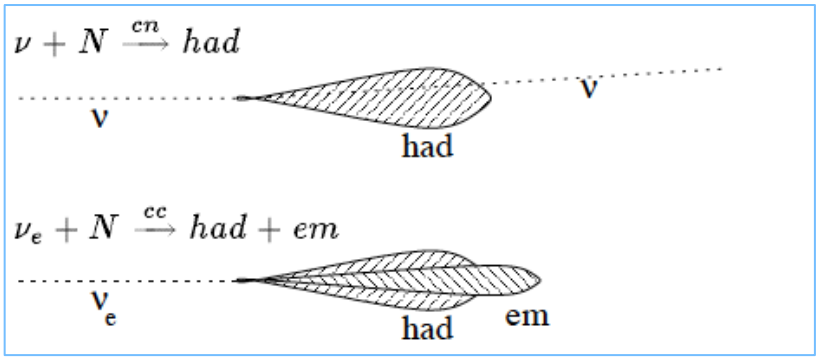
google also: ‘The KM3NeT Virtual Reality Experience’

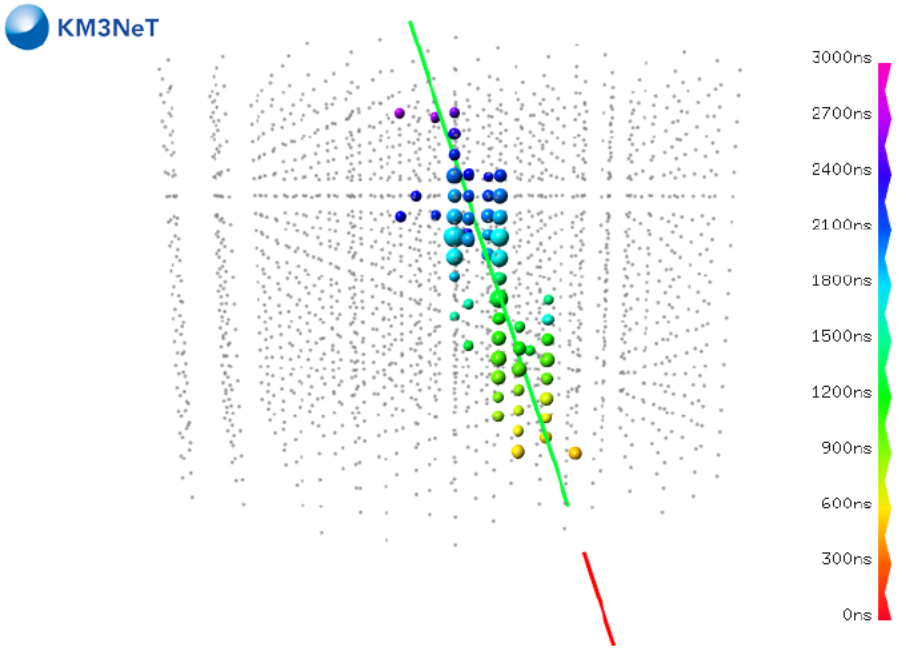
Event Topologies

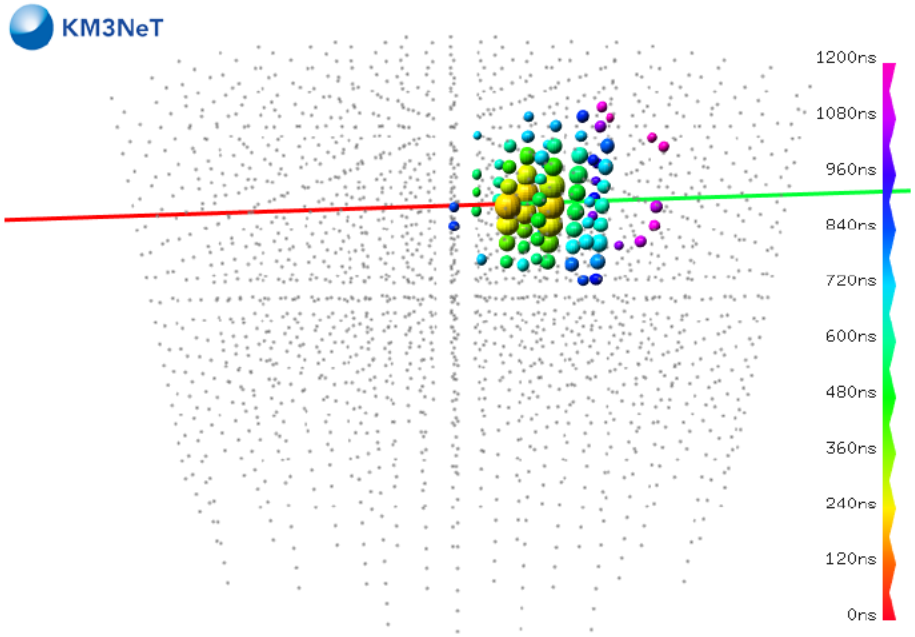
Track-like (ν_μ CC)



shower-like (ν NC, ν_e CC)

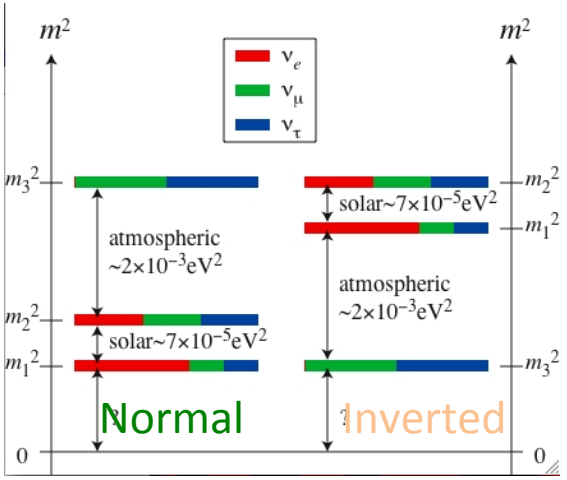


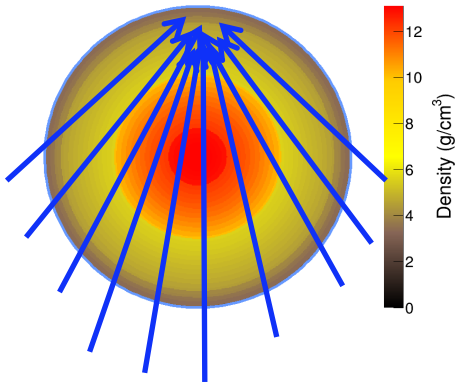


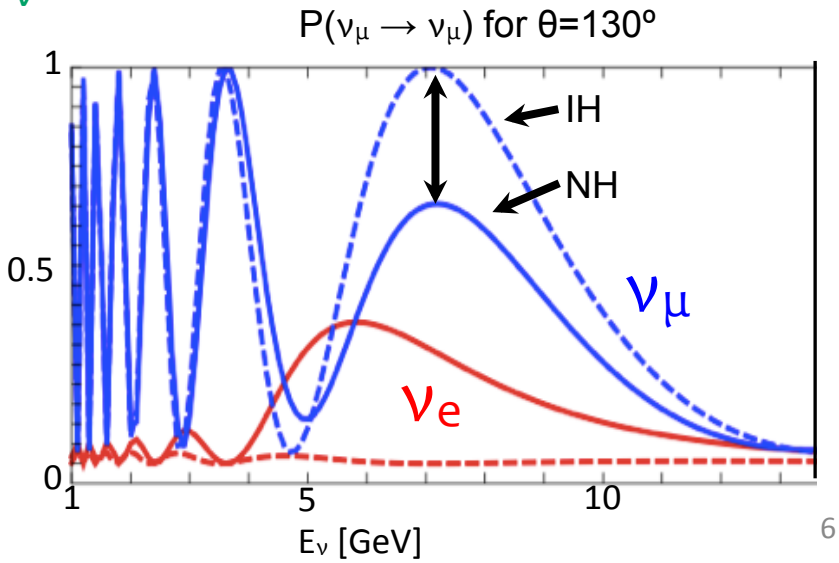


NMH with Atmospheric Neutrinos

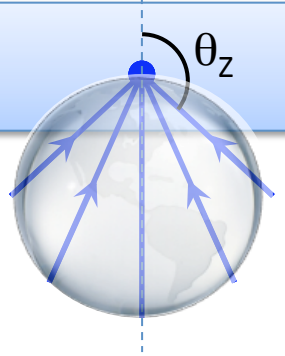
- A ¨free beam¨ of known composition (ν_e, ν_μ)
- A ¨free cavern¨ of known/uniform composition
- Wide range of baselines and energies
- Oscillation pattern distorted by Earth matter effects maximum difference IH ⇔ NH for resonance in Earth mantle: θ=130° (7645 km) and E_ν = 7 GeV







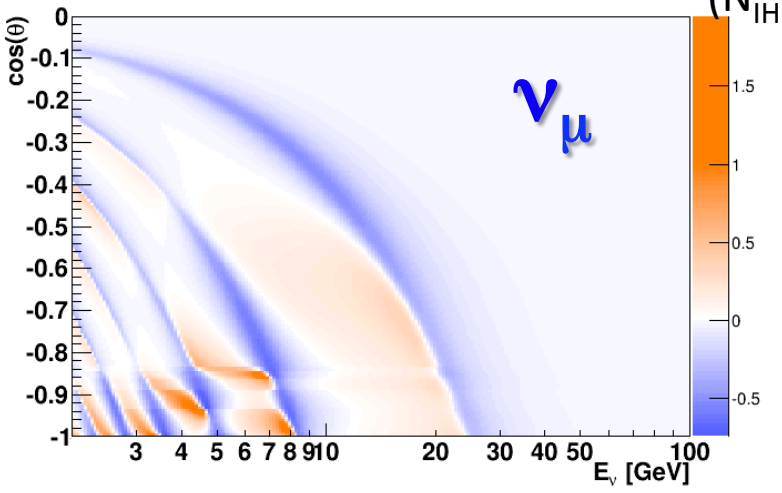
ORCA NMH Experimental Signature

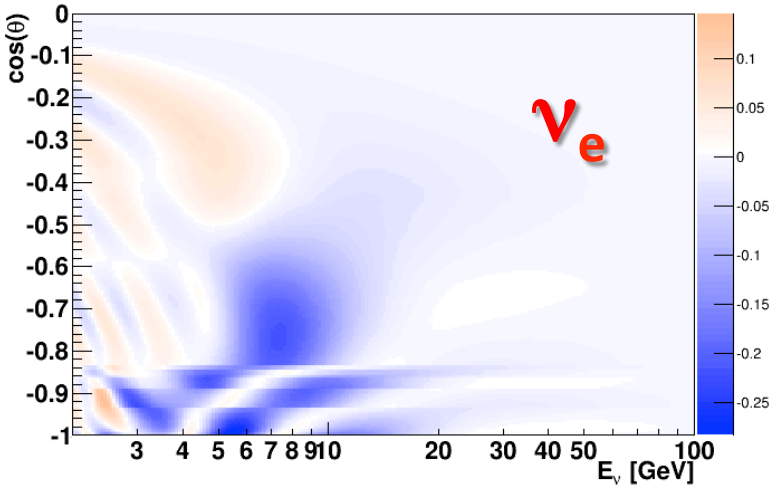


Both muon- and electron-channels contribute to hierarchy asymmetry

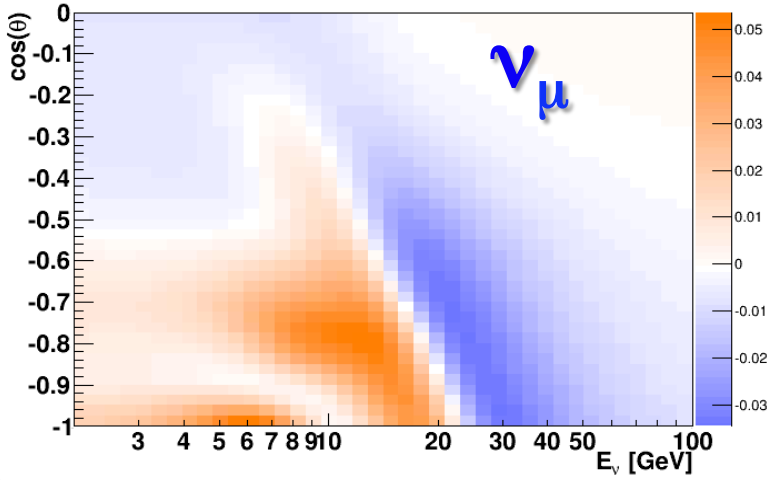
Electron channel more robust against detector resolution effects

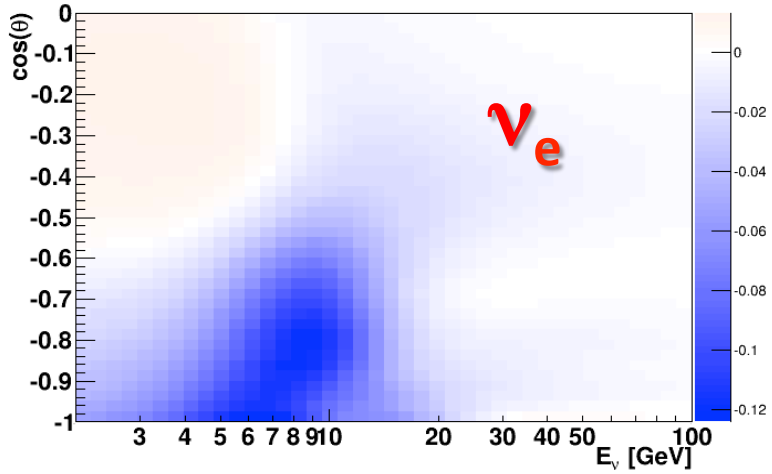
$(N_{IH}-N_{NH})/N_{NH}$





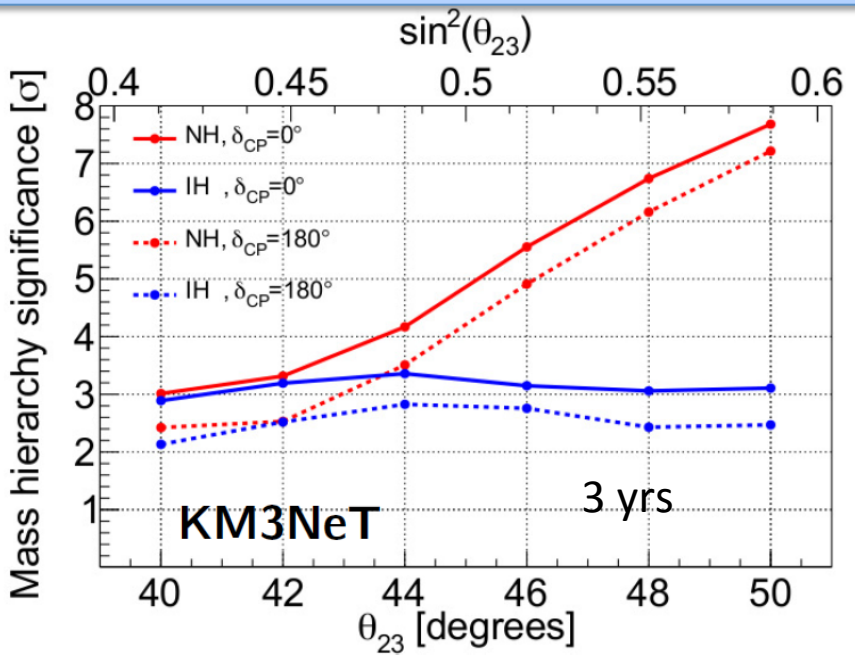
ORCA E,θ resolutions

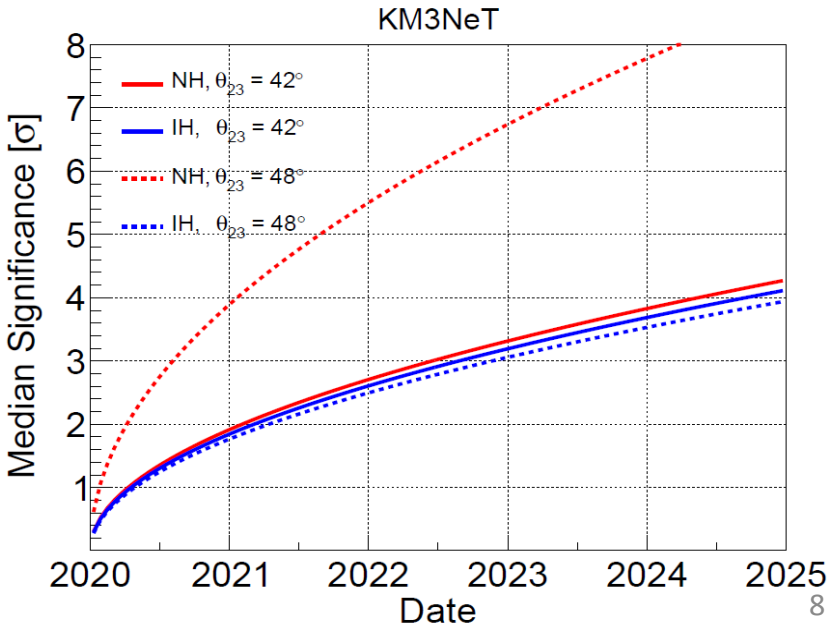




ORCA Sensitivity to Mass Hierarchy

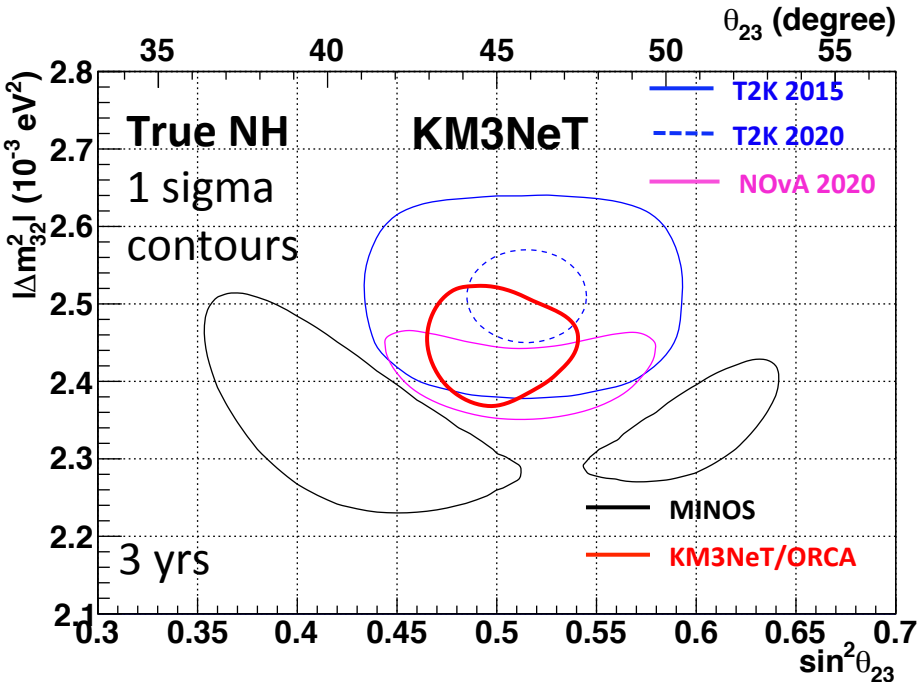
- ~3σ MH sensitivity in 3 years
- For IH, sensitivity is essentially independent of θ_{23}
- The combination of NH and upper octant of θ_{23} gives significantly improved sensitivity (>5σ in 3 years)
- The value of δ_{cp} has small but non-negligible impact on sensitivity



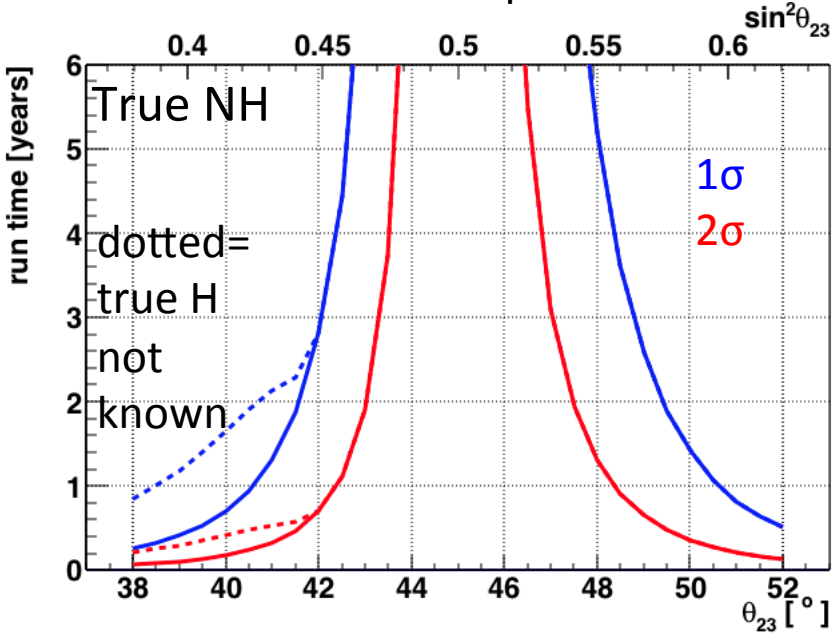


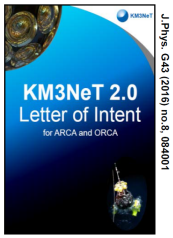
ORCA Measurement of Δm^2_{32} and $\sin^2\theta_{23}$

- 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



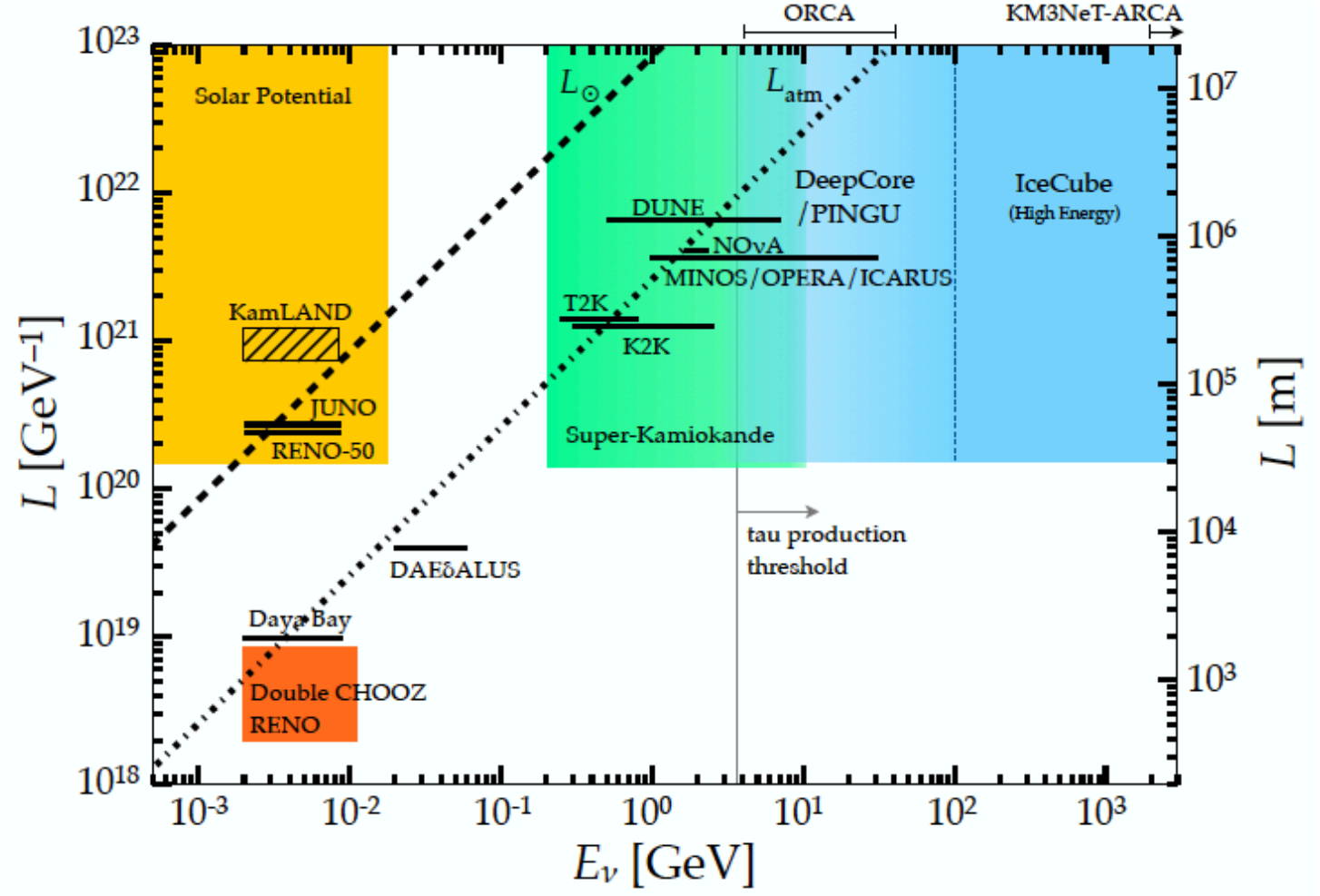
Time to measure quadrant





KM3NeT 2.0: Letter of Intent
http://dx.doi.org/10.1088/0954-3899/43/8/084001
J. Phys. G: Nucl. Part. Phys. 43 (2016) 084001

Oscillation Physics



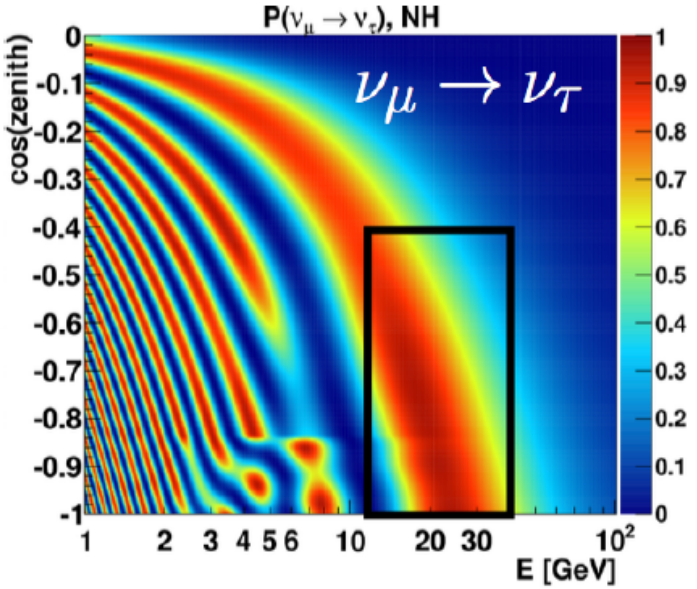
Baselines and energies inaccessible to LBL or reactor neutrino experiments

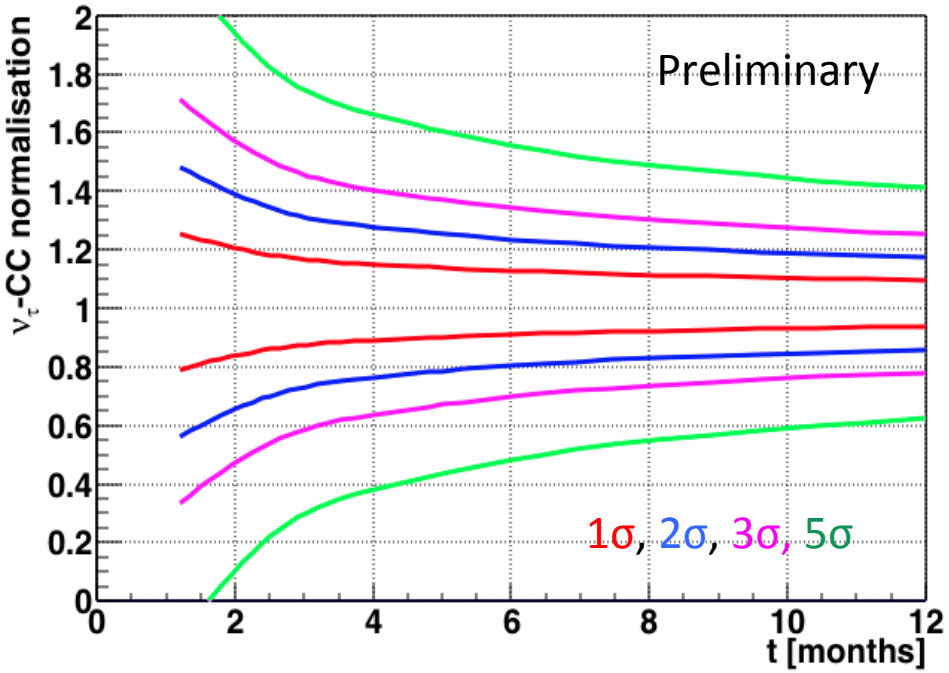
Very different systematics

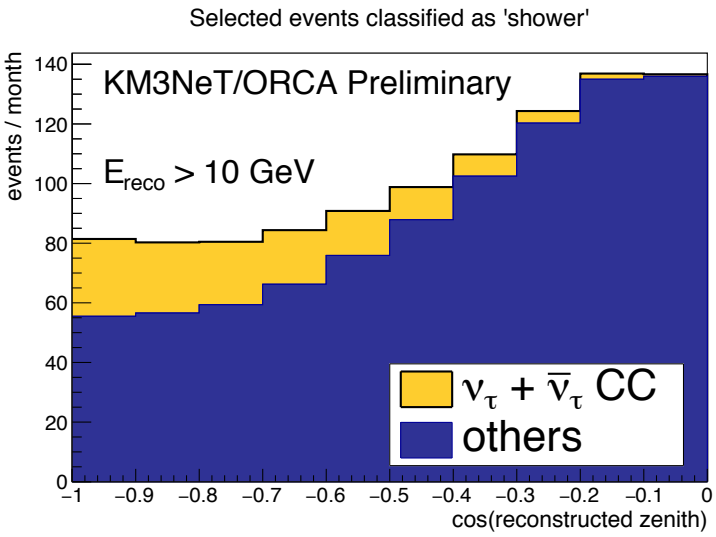
Above tau production threshold

ORCA Tau Neutrino Appearance

- ν_τ appearance tests PMNS unitarity and BSM theories
- 30% deviations allowed by world data
- ≈3k ν_τ CC events/year with full ORCA
- Rate constrained within ≈10% in 1 year



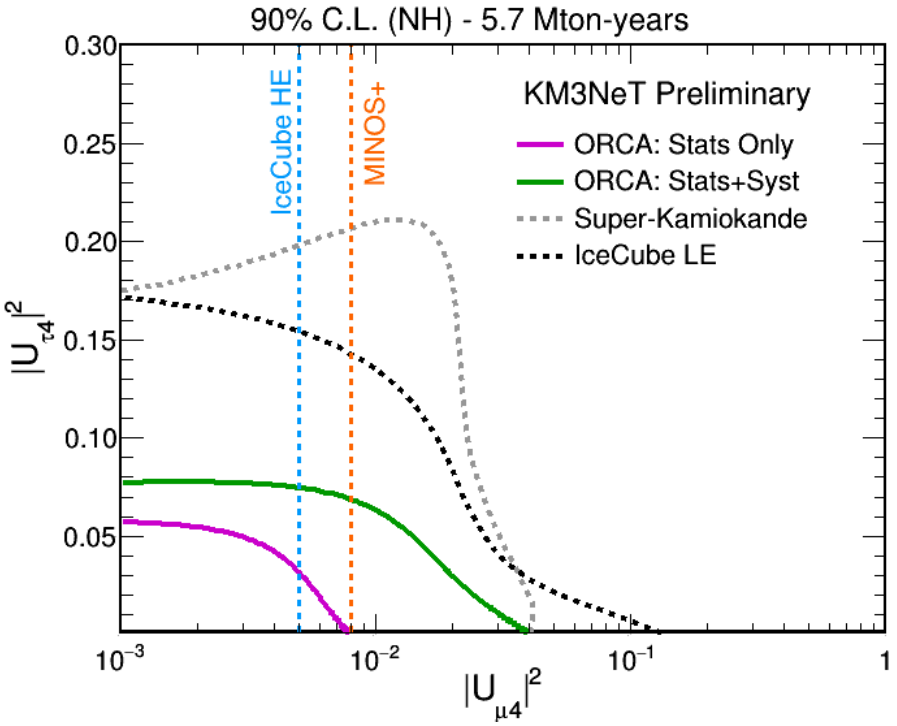


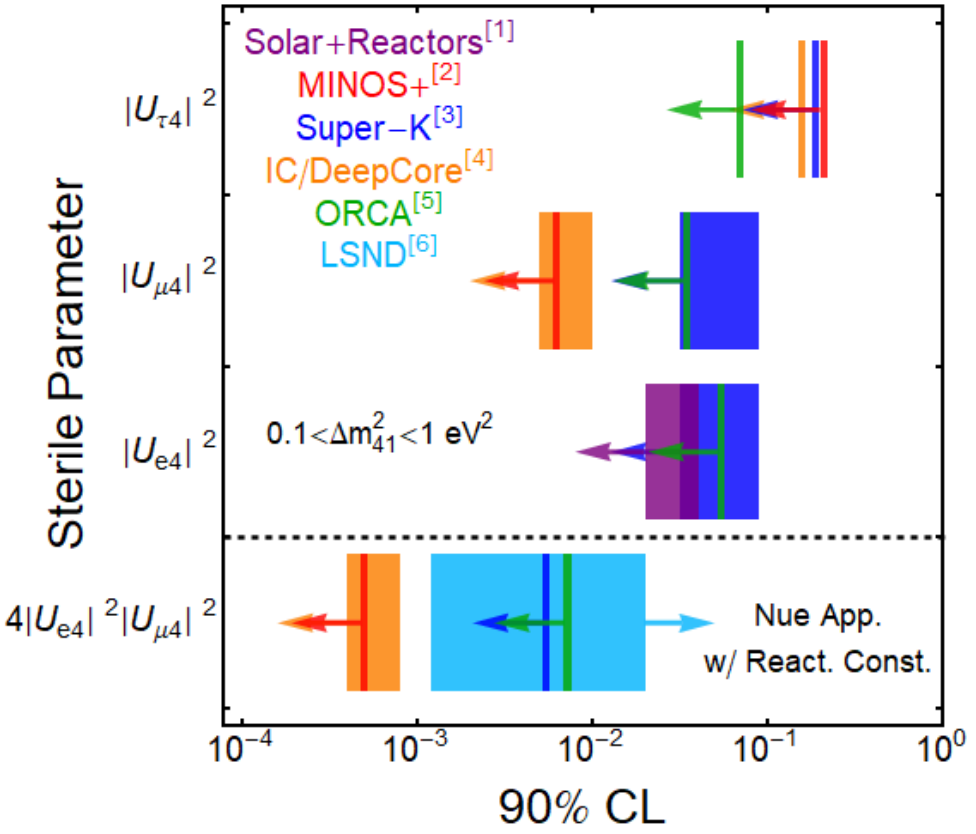


Light Sterile Neutrino

- Promising sensitivity in $U_{\tau 4}$ mixing
- Factor of two better sensitivity than current limits from SK and IC
- After only 1 year of data taking

[1] PRD 85, 077301 (2012); PRL 117, 151801 (2016)
[2] J. J. Evans, Neutrino 2016; PRL 117, 151803 (2016)
[3] Phys. Rev. D 91, 052019 (2015)
[4] PRL 117, 071801 (2016); arXiv:1702.05160 (2017)
[5] KM3NeT-ORCA Preliminary
[6] Phys. Rev. D 64, 112007 (2001)

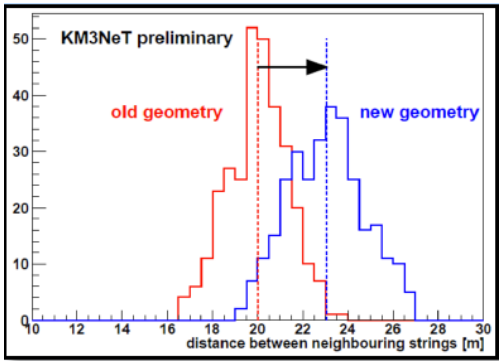




Improvements Since LoI: Geometry+Trigger

Geometry:

Geometry	Vertical spacing (between DOM)	horizontal spacing (between strings)
LoI-based [3]	9 m on average with alternate 6 m and 12 m	20 m
New	9 m	23 m

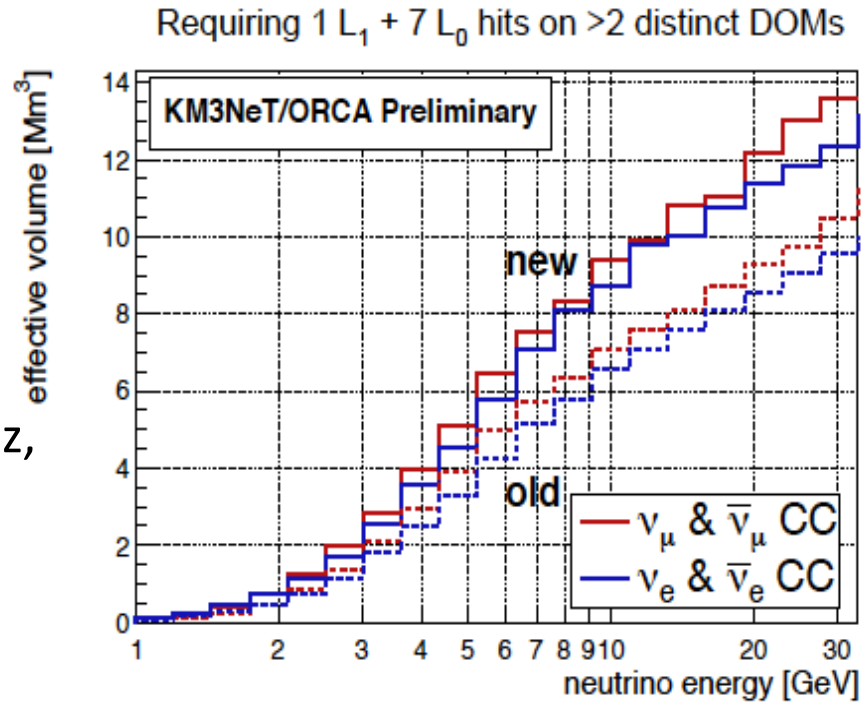


New "MX" trigger:

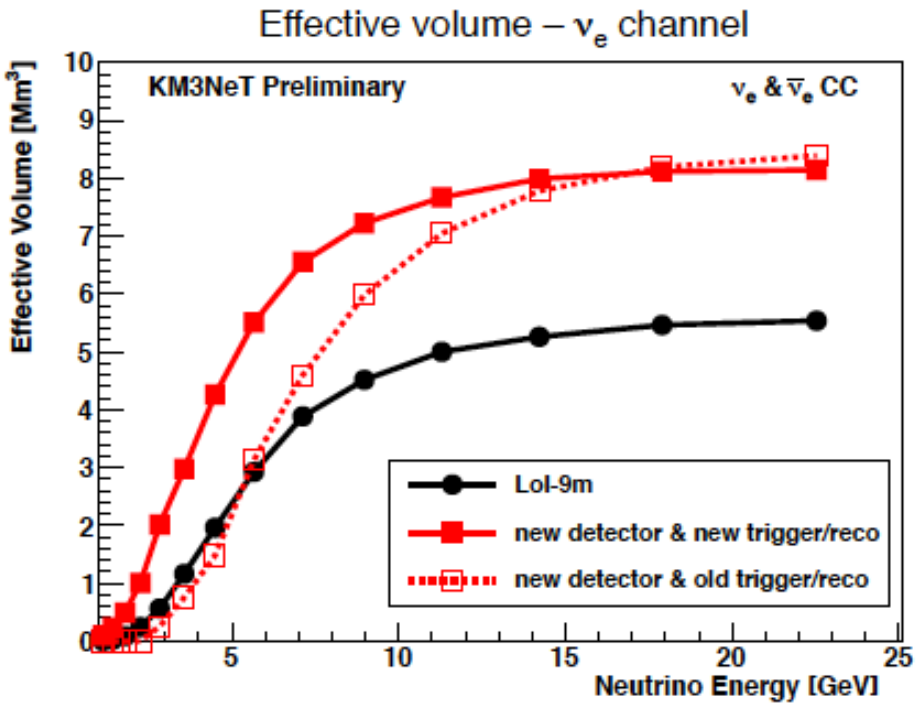
require one local coincidence (L1)
+ causally connected L0 hits on neighbouring DOMs

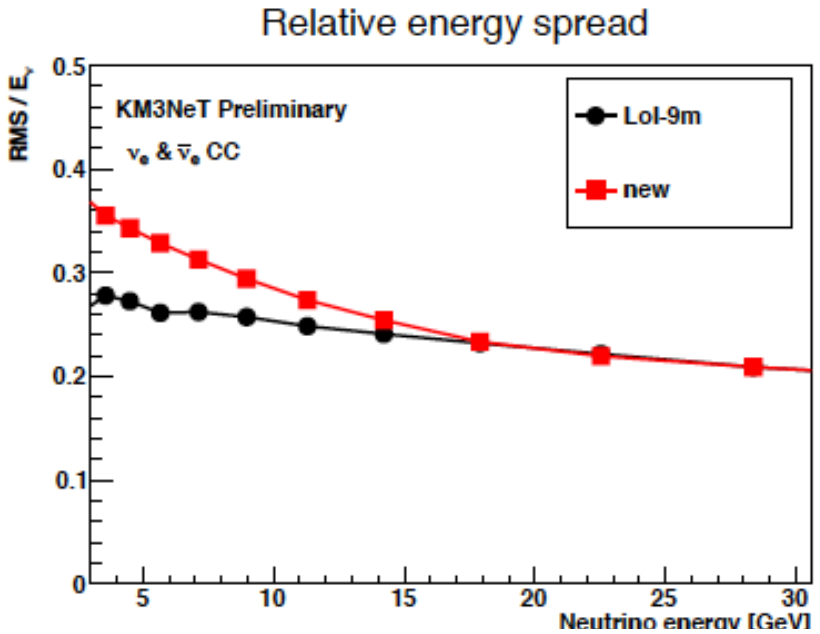
Keeping bandwidth requirements:
trigger rate from pure noise is kept at ~20Hz, way below atmospheric muons (~50Hz)

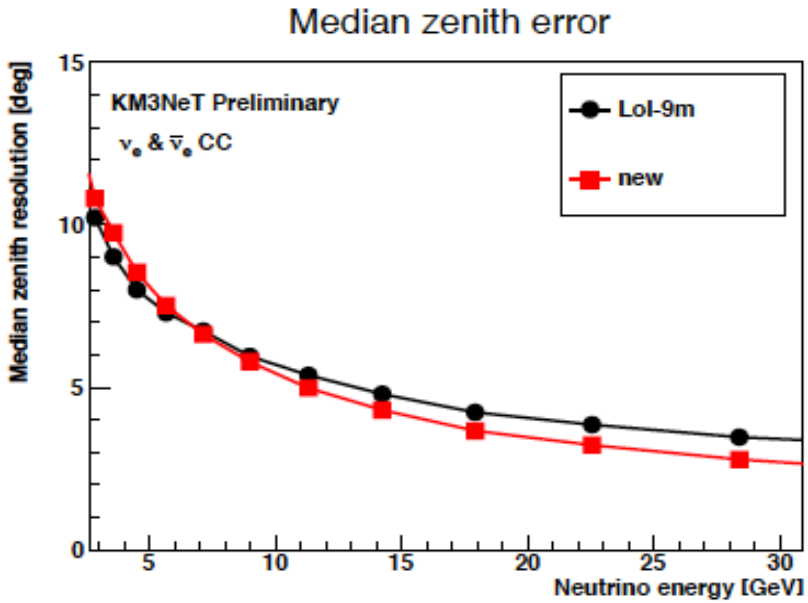
In few-GeV region, gain close to a factor 2 in triggered events



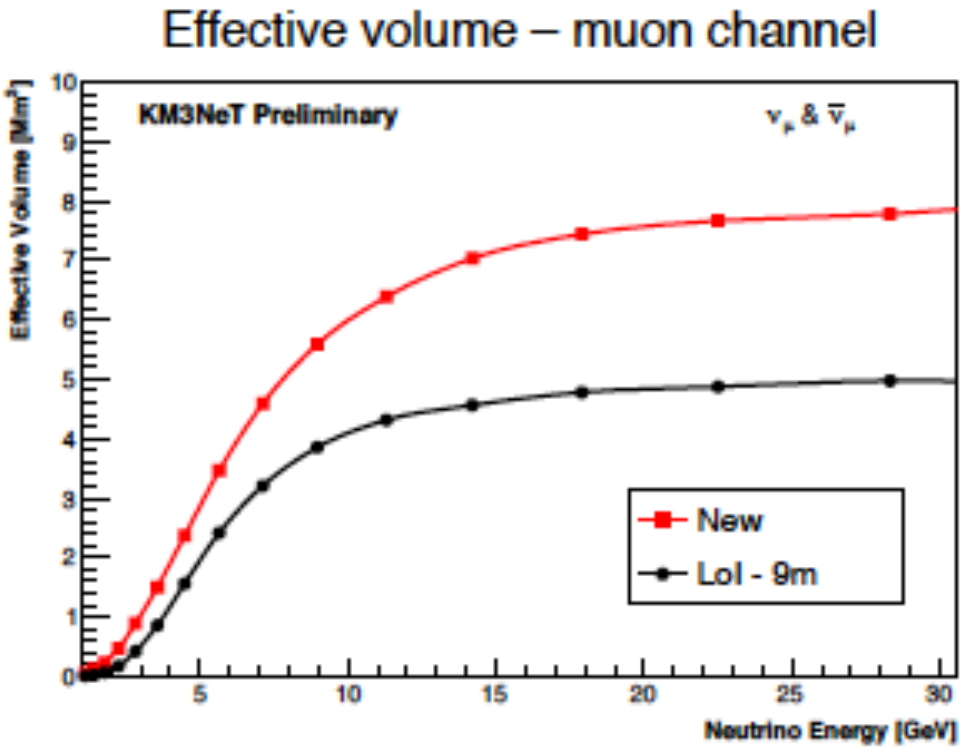
Improvements Since LoI: Shower Reconstruction

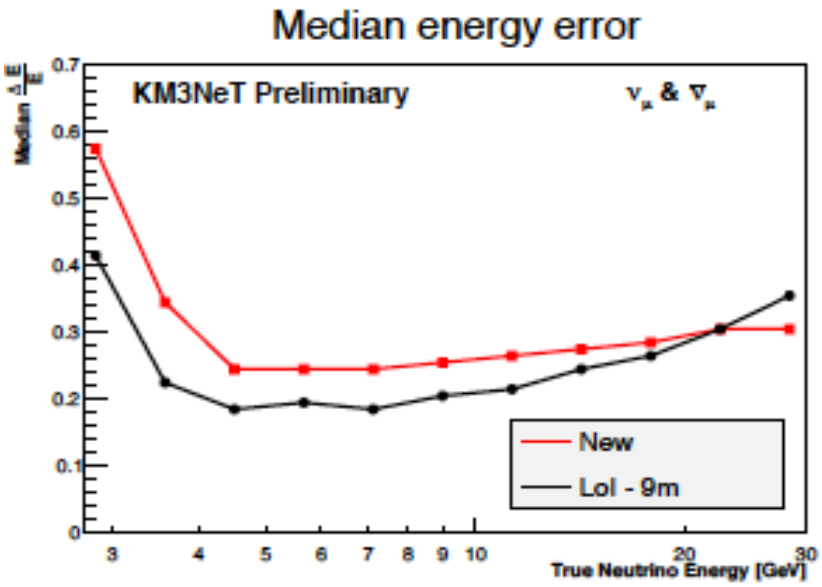


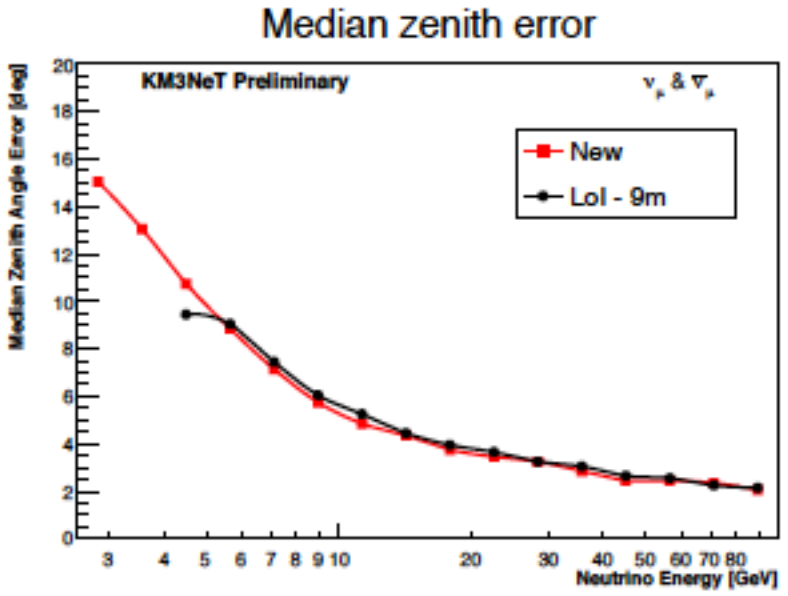




Improvements Since LoI: Track Reconstruction

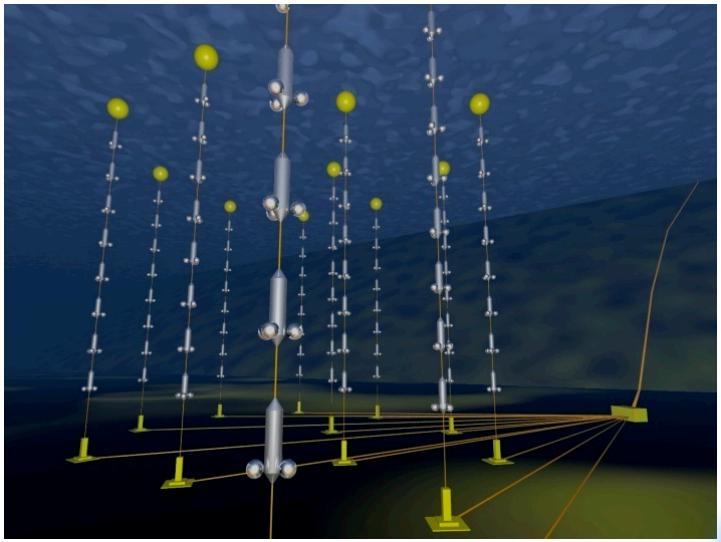


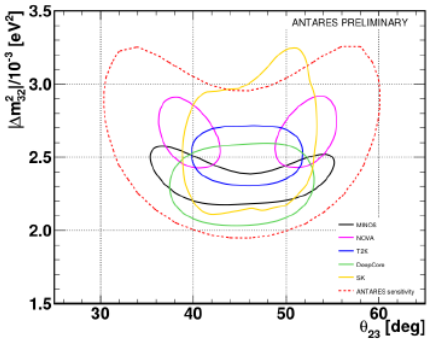




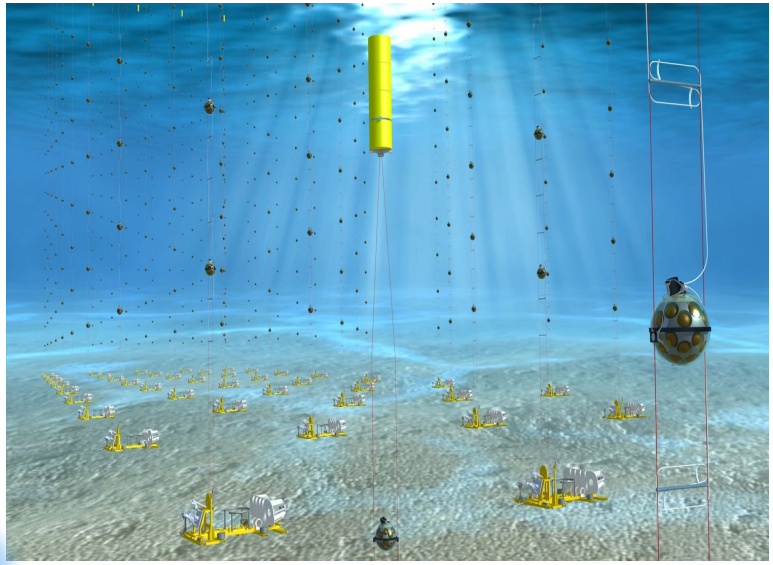
ANTARES -> KM3NeT 2.0

12 lines, 900 OMs





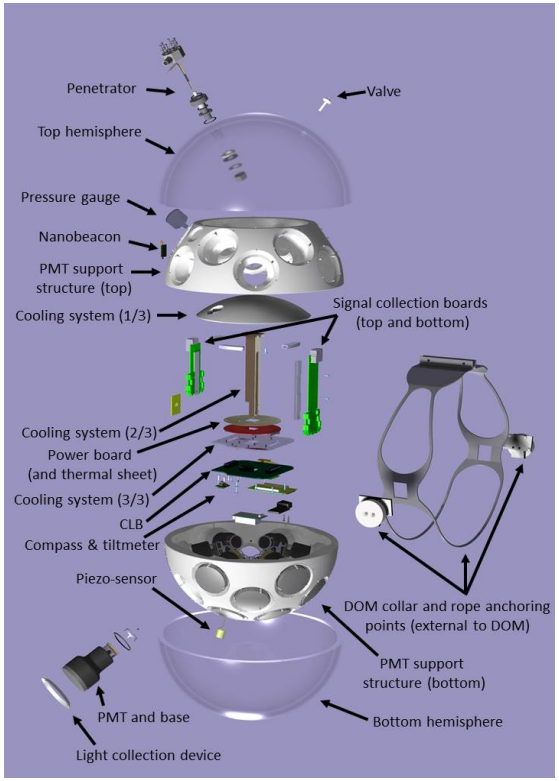
3 Building Blocks (3*115 lines, ~3*2000 OMs)



- 31 x 3” PMTs
- Uniform angular coverage
- Directional information
- Digital photon counting
- Reduced ageing

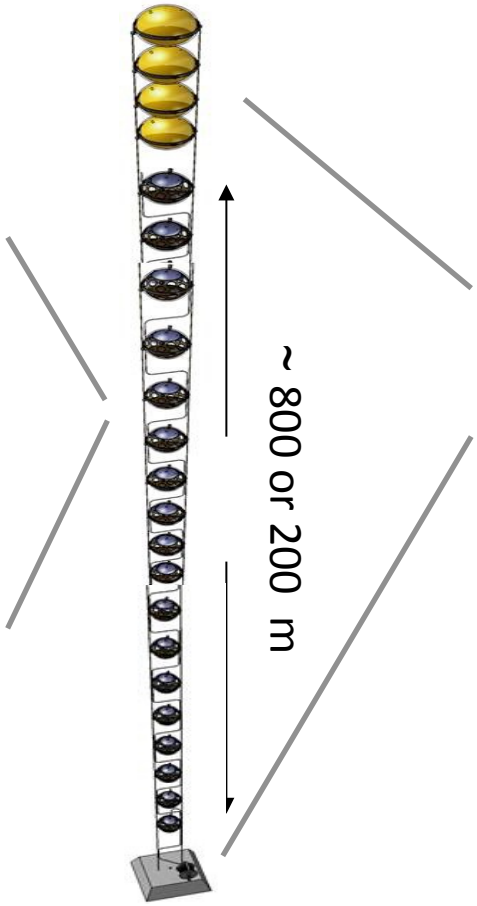
KM3NeT Technology

Digital Optical Module



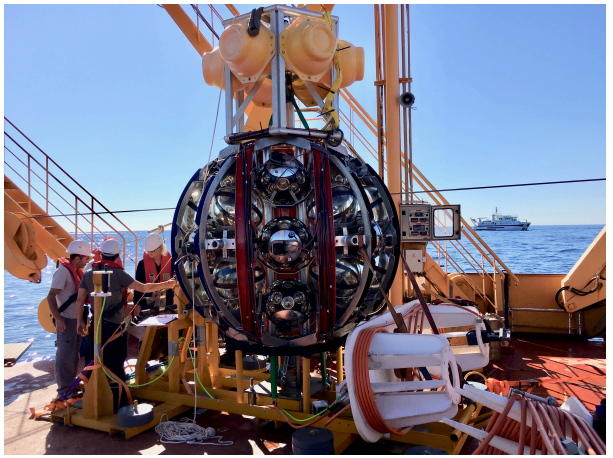
- All data to shore
- Gbit/s on optical fibre
- Hybrid White Rabbit
- LED flasher & acoustic piezo
- Tiltmeter/compass

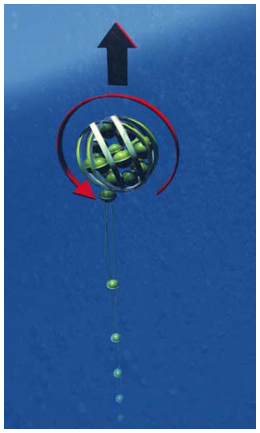
String



- 2 dyneema ropes
- Oil filled PVC tube
- Low drag
- Low cost

Deployment Vehicle



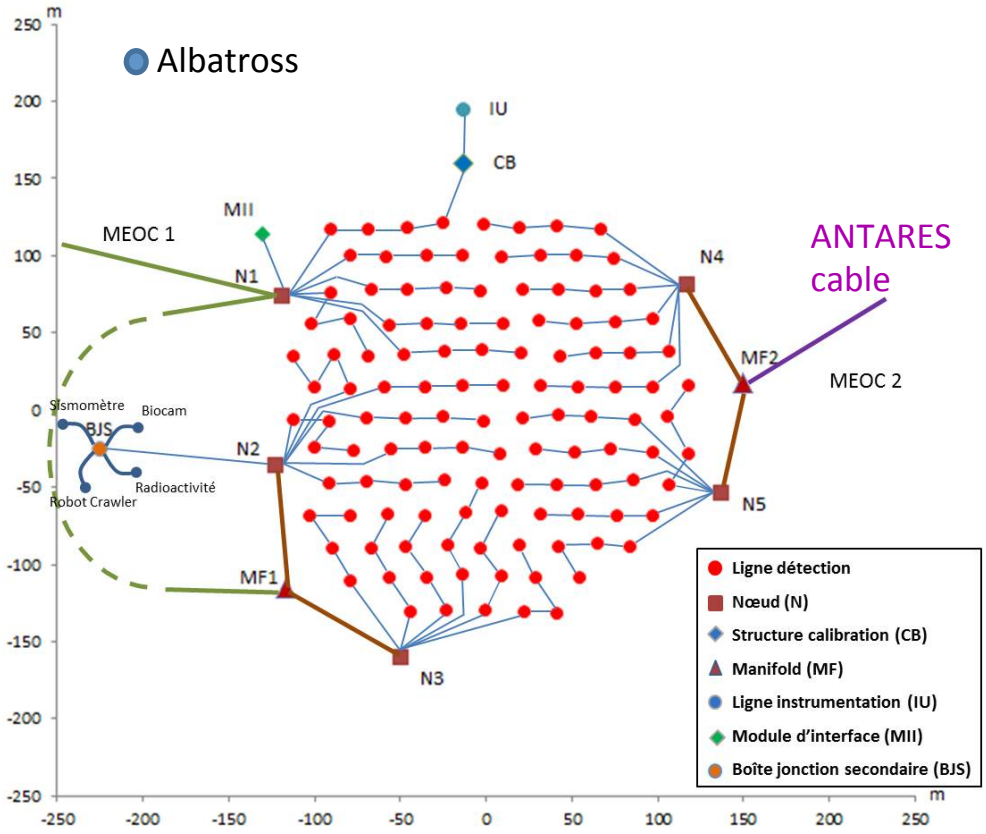


- Rapid deployment
- Multiple strings/sea campaign
- Autonomous/ROV unfurling
- Reuseable

ORCA Status

Phase 1: 7 string array at KM3NeT-France site to demonstrate technology/detection methods in the GeV range

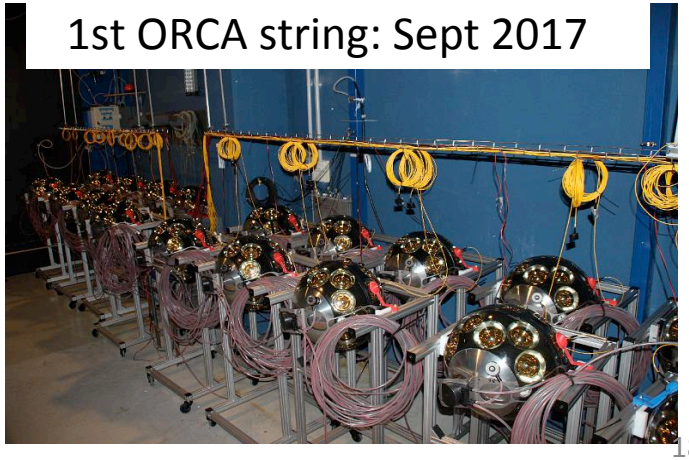
Phase 2: Deploy 1 building block (115 strings)



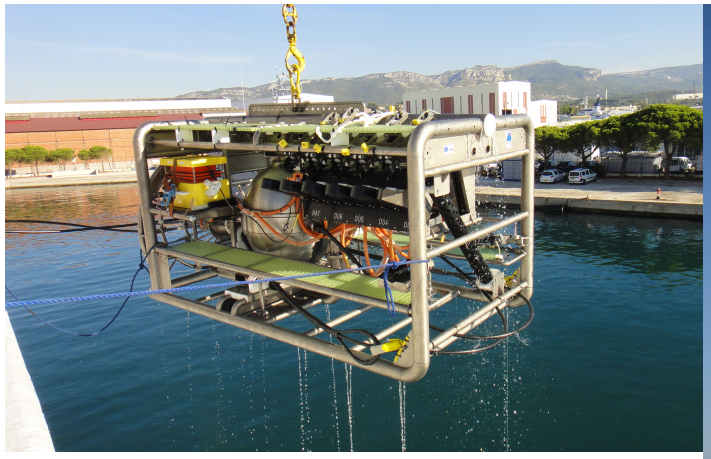
MEOC: Dec 2015, July 2017

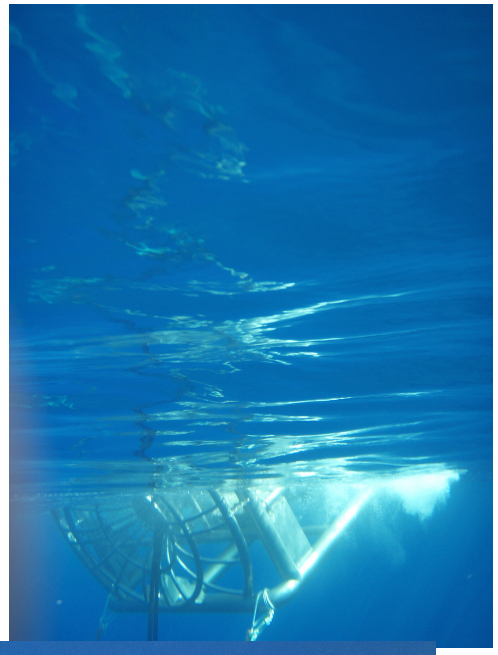
1st node: May 2015, Sept 2016

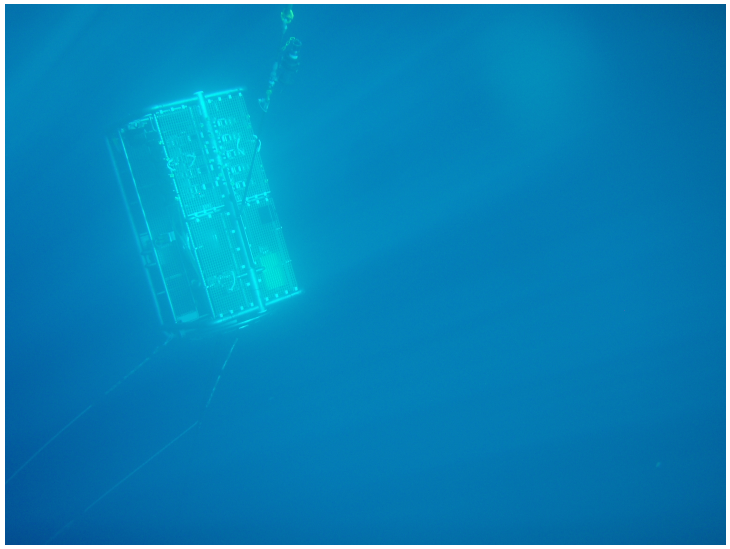
1st ORCA string: Sept 2017

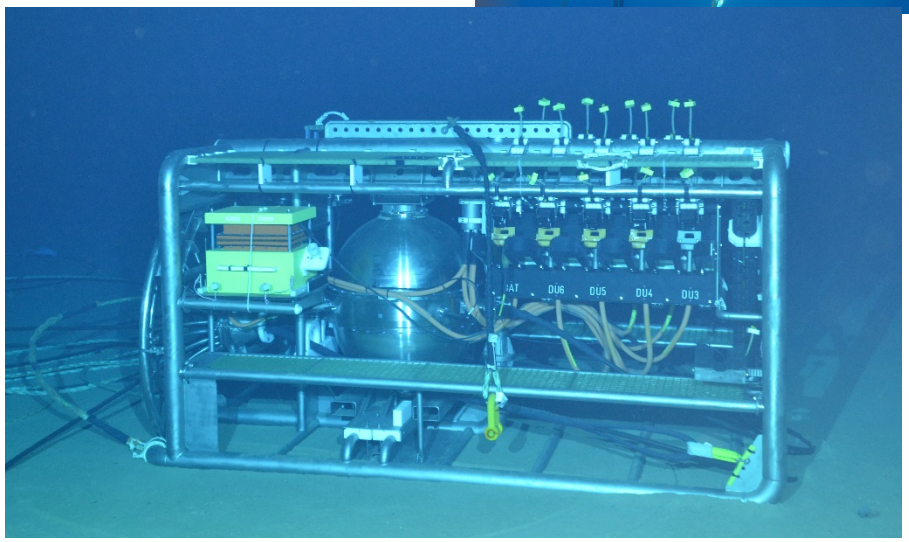


ORCA Junction Box Re-deployment (29 Sept 2016)



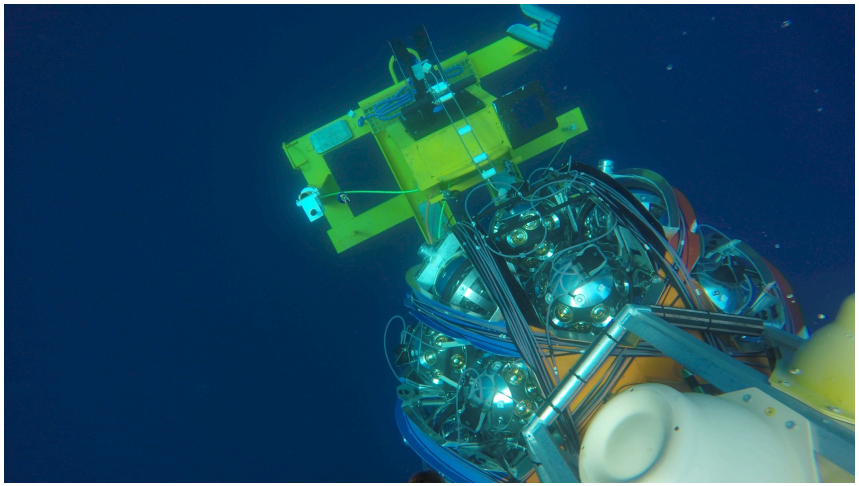


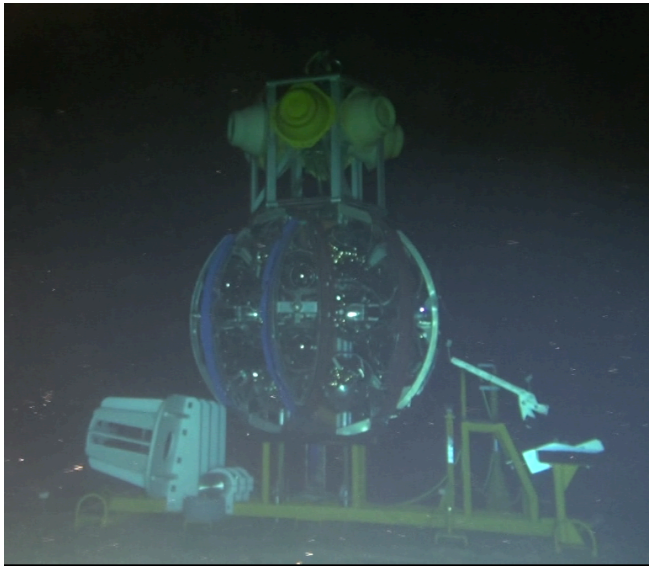


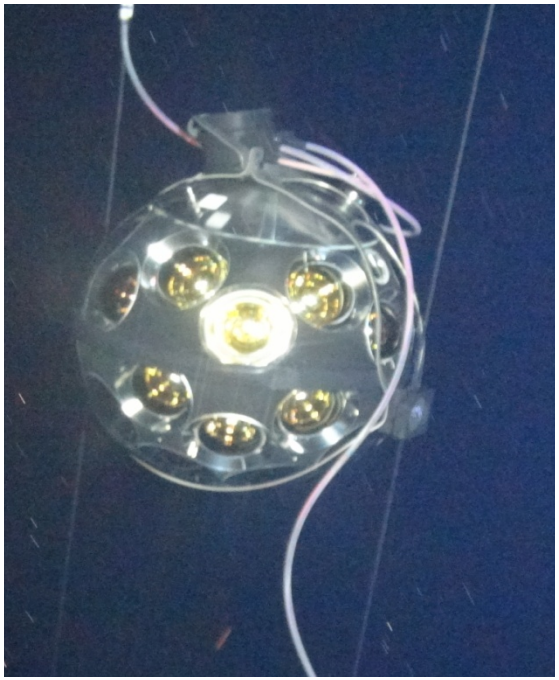


Operational, but fault developed in deep sea cable

String Deployment

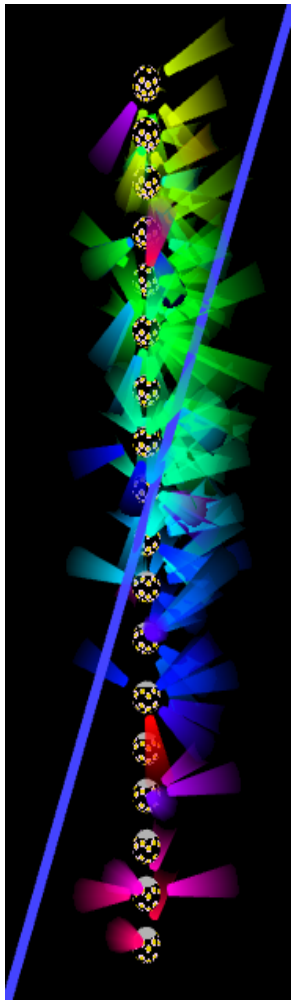


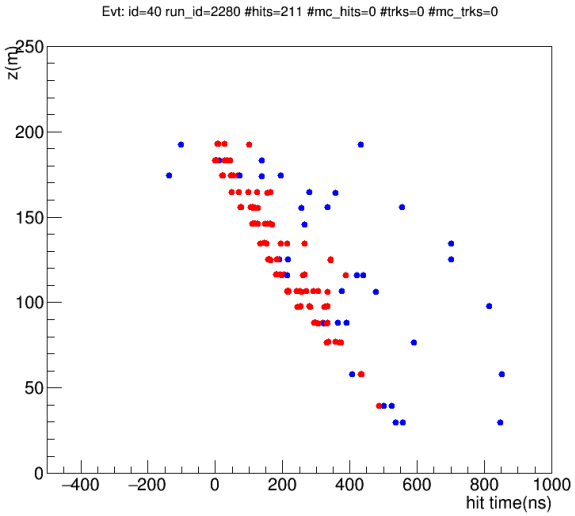




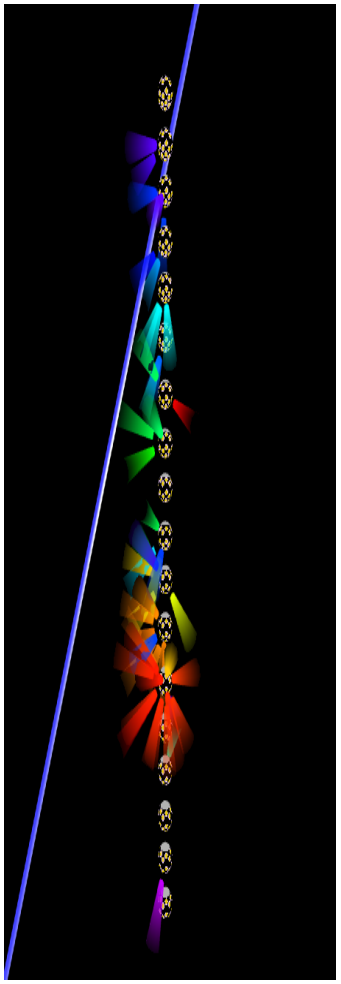
First ORCA Events

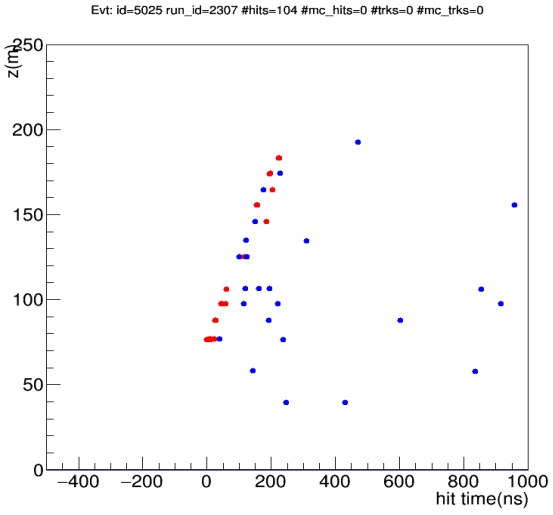
Atmospheric Muon Bundle



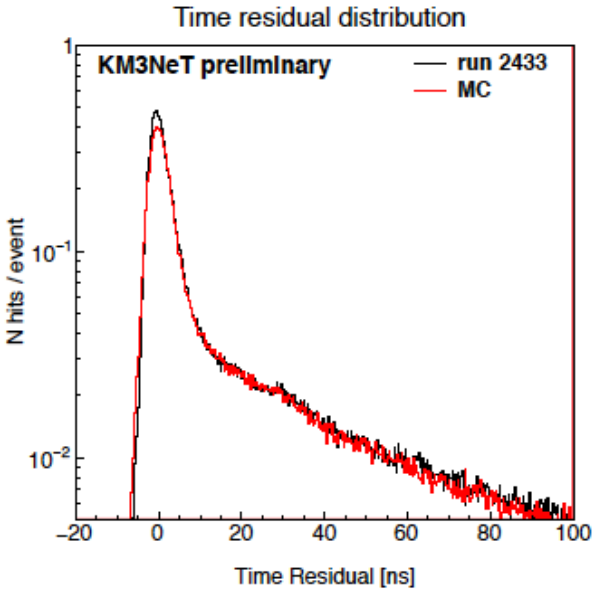


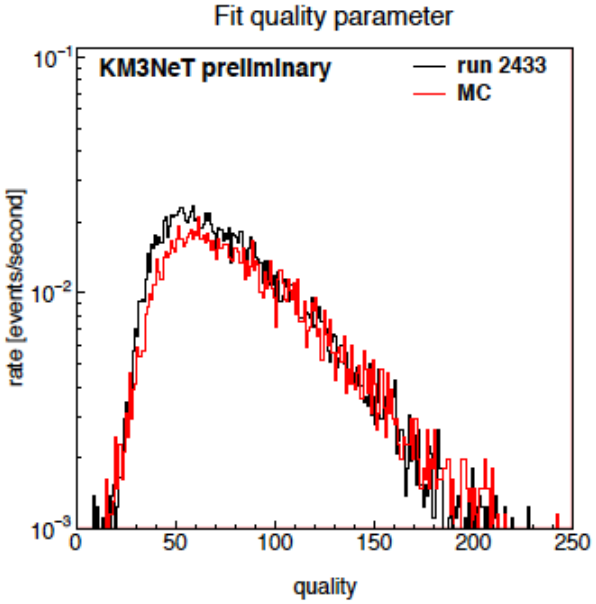
Starting Neutrino Candidate

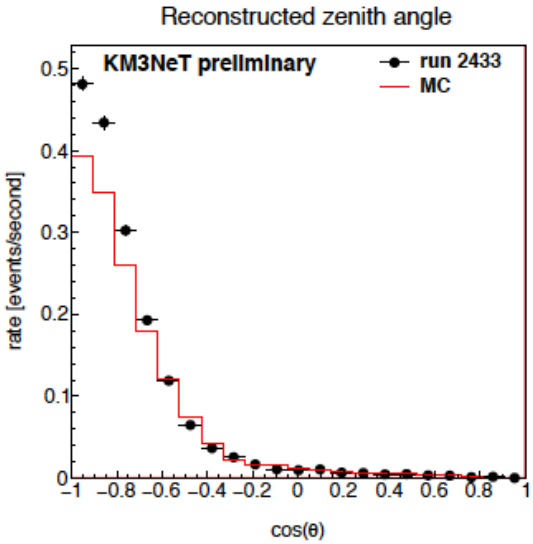




ORCA: Data vs MC





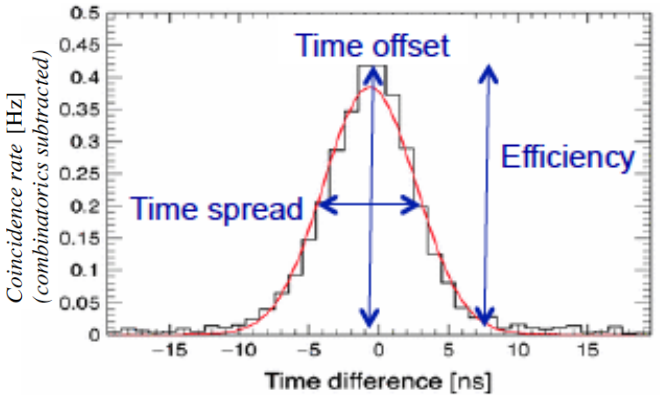


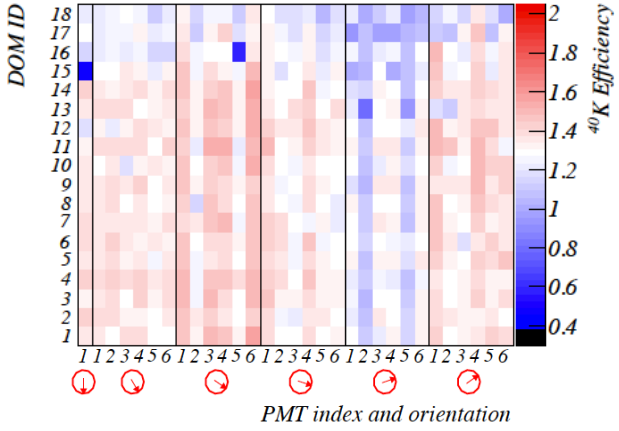
^{40}K: Inter-PMT Calibration

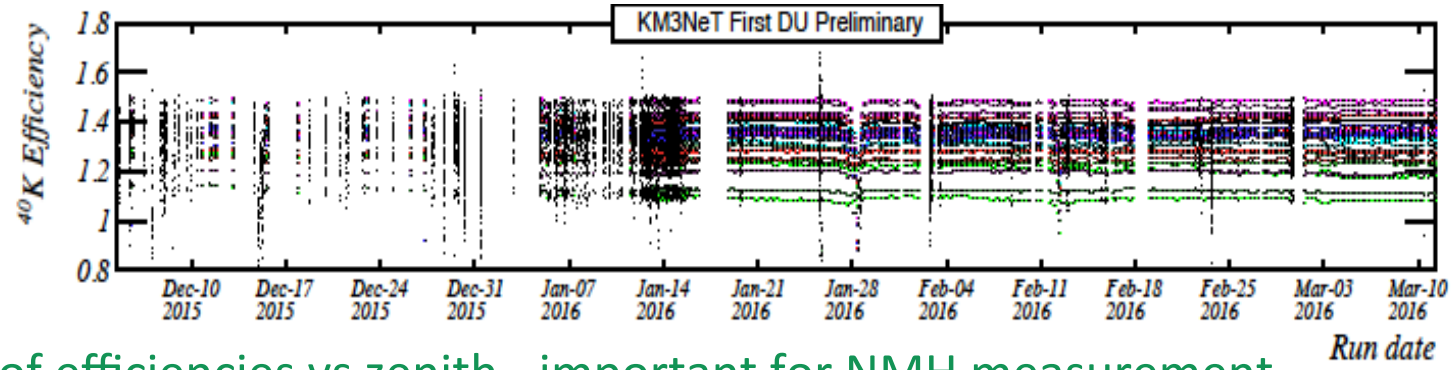
^{40}K → e$^-$ (β decay)

^{40}Ca

Up to 150 Cherenkov photons per decay; stable ^{40}K concentration

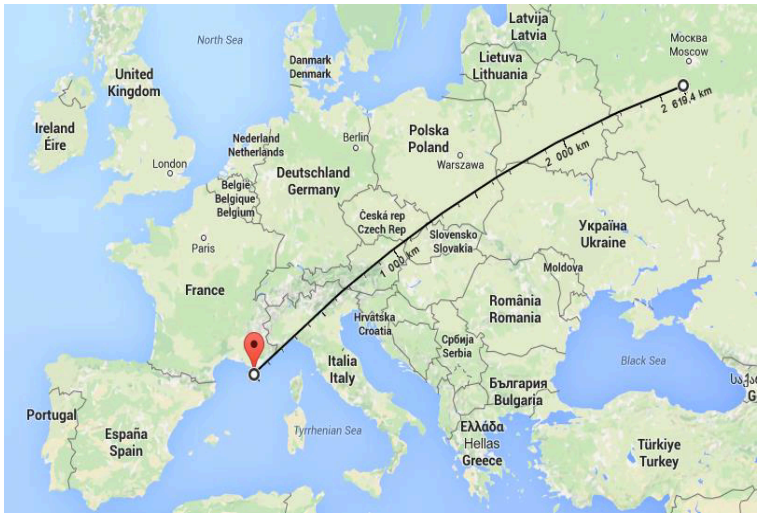






Knowledge of efficiencies vs zenith - important for NMH measurement

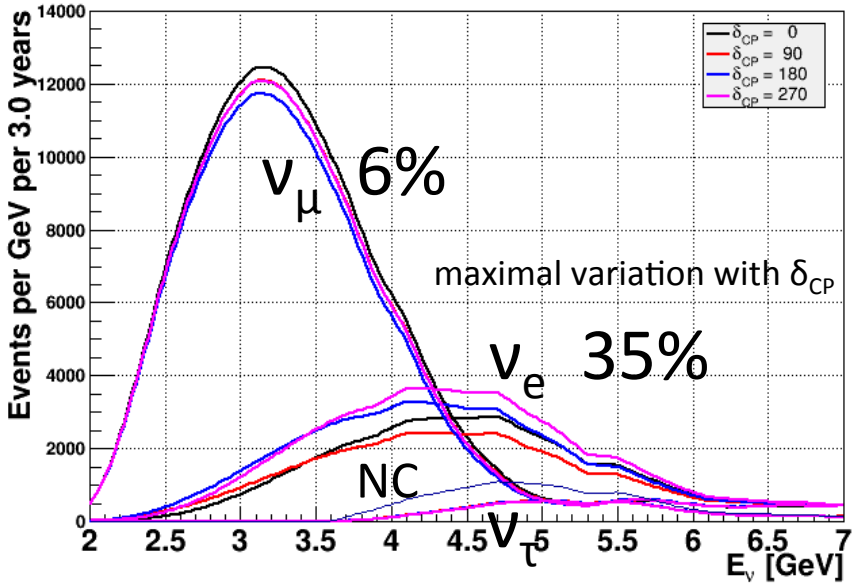
Protvino to ORCA (P2O): prelim. study

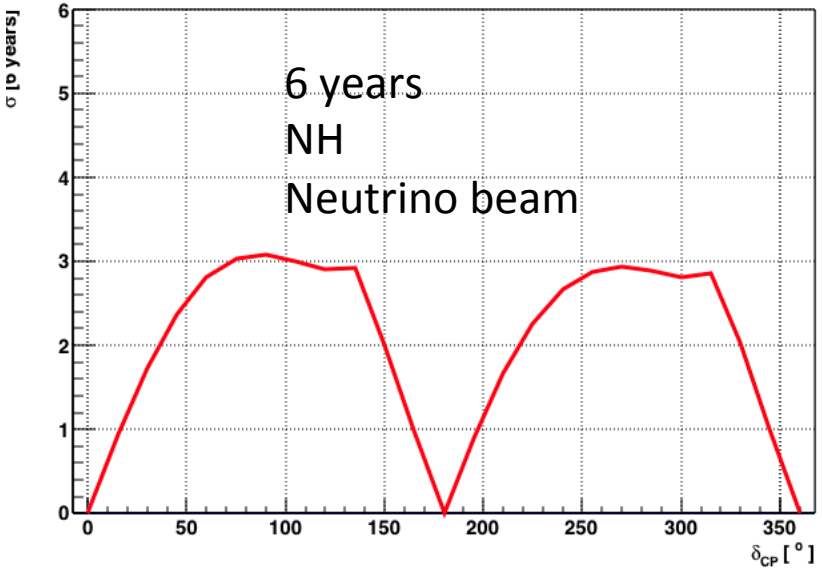


U70 accelerator in Protvino (Moscow), E=70 GeV

- ν_e appearance at **L = 2600 km**
- Optimal baseline for separating NMH from δ_{CP}
- Target energy range : **3-8 GeV**
- P = 15 kW -> **450 kW** (up to **4.10^{20} POT/year)**
- 12° angle, near detector@ -60m

Similar sensitivity to DUNE





Outlook

KM3NeT: phased construction of a next-generation neutrino telescope

Developed novel and performant multi-PMT technology
interest from IC-Gen2, CHIPs, NuPrism, HyperK, …

ARCA-high energy:

- unprecedented angular resolution/multi-flavour astronomy
- investigation of diffuse flux and point-like sources

ORCA-low energy:

- 1st Node +1st string operational (115 by 2020)
- NMH at 3 sigma level in 3 years (IH, NH/first octant)
  Much quicker if NH/second octant
- Competitive measurements of Δm^2_{32} and $\sin^2\theta_{23}$, tau appearance, sterile neutrinos, NSI, DM, tomography,…

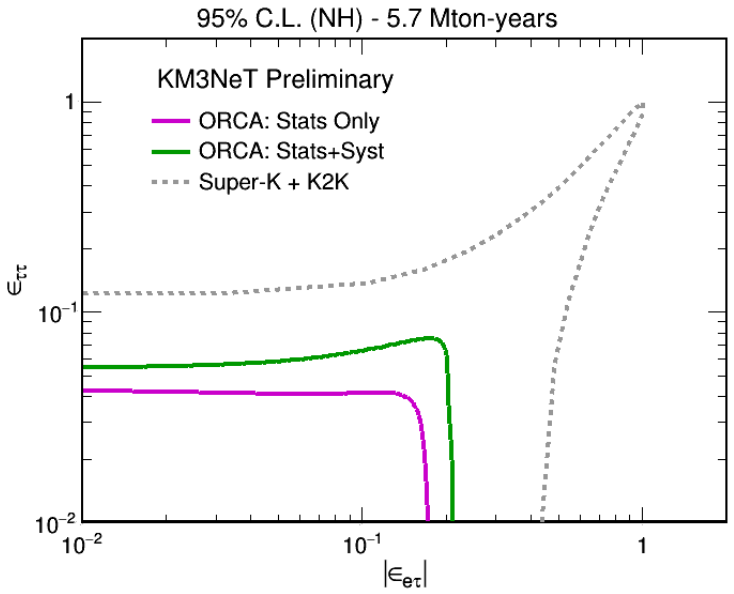
CP Violation?:

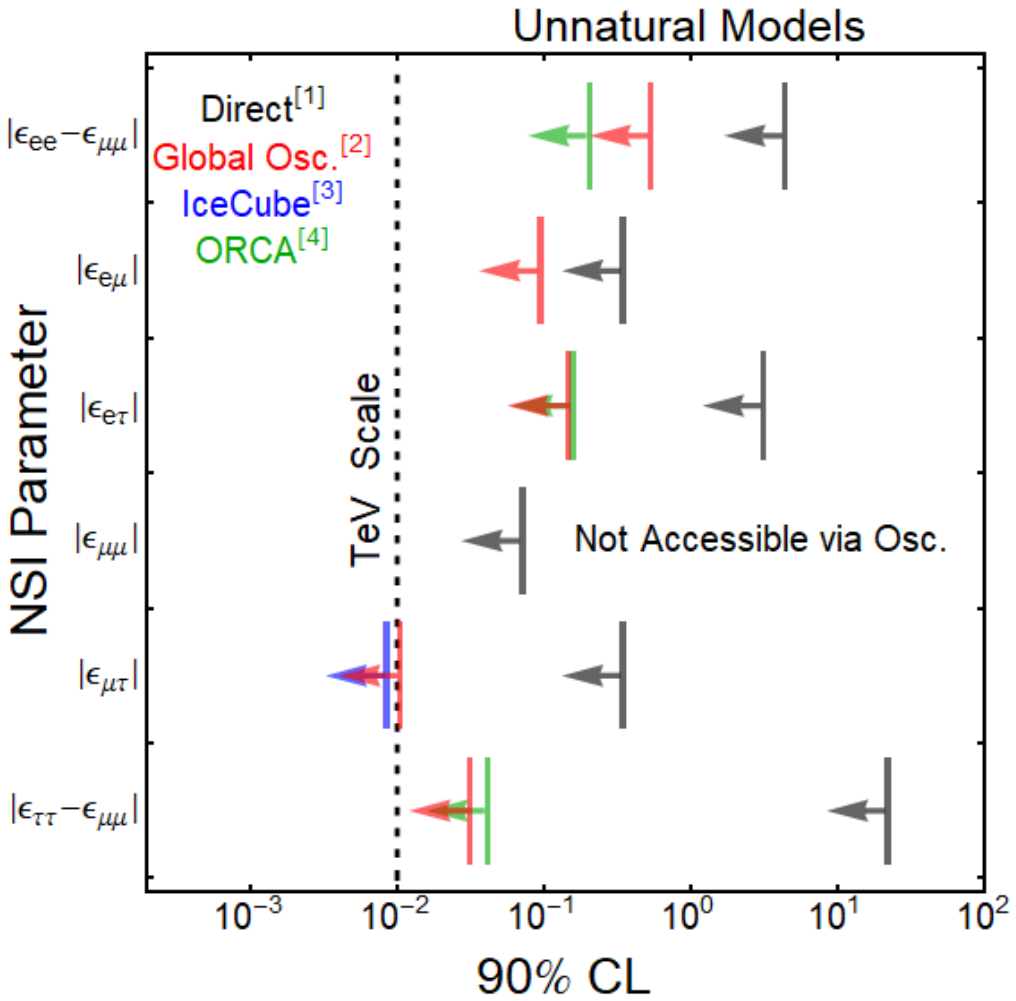
- P2O: Protvino beam to ORCA

New collaborators very welcome

Non-Standard Interactions

- ORCA sensitive to NSI effects of order 10% of the Fermi int.
- Direct bounds are more than 10x larger in some cases
- ORCA improves over current atmospheric scale bounds
- Limits competitive with global limits from oscillation





[1] JHEP 0908:090 (2009)
[2] JHEP 1309:152 (2013)
[3] arXiv:1709.07079 [hep-ex]
[4] KM3NeT-ORCA Preliminary