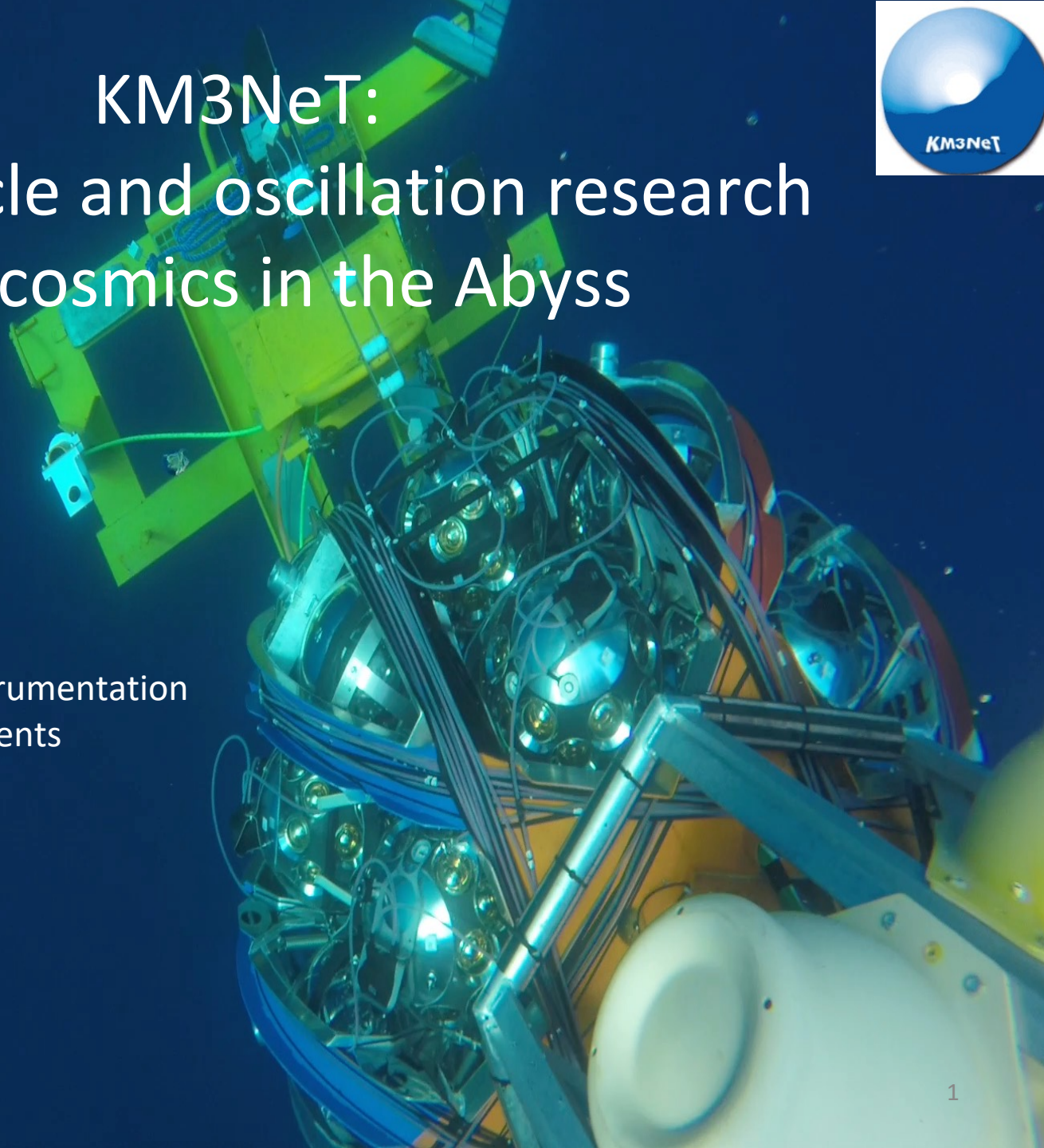
KM3NeT: Astroparticle and oscillation research with cosmics in the Abyss

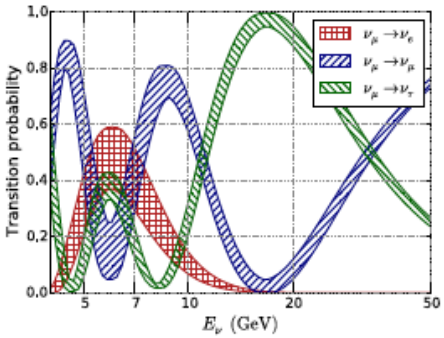


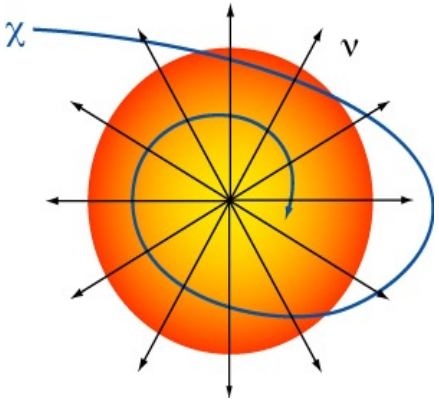
Workshop on the evolution of advanced electronics and instrumentation for Water Cherenkov experiments

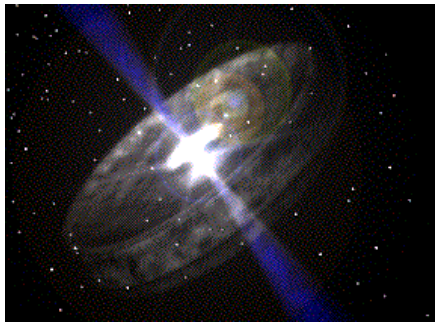
Paschal COYLE, CPPM
11/4/22

Neutrino telescopes: science

MeV to PeV energies







Supernova
Solar flares

Atmos neutrinos
ν oscillations
ν mass ordering
Sterile, NSI, …

Dark matter
Monopoles,
Nuclearites,…

Cosmic neutrinos

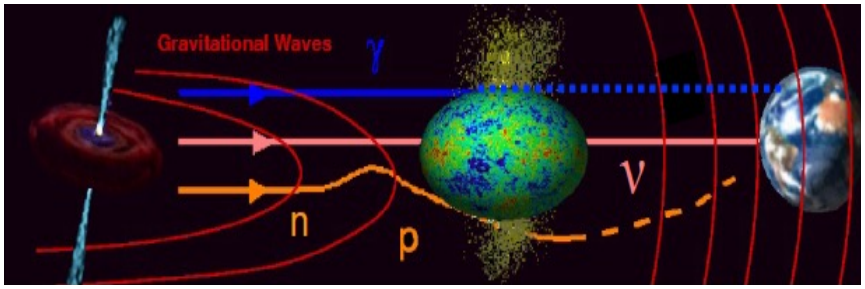
Cosmic rays

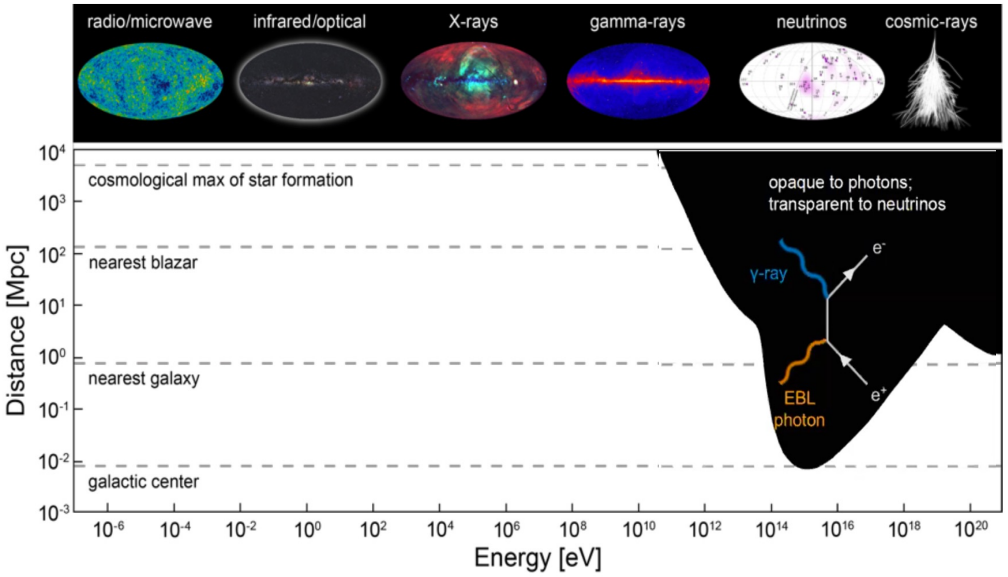
Origin and production mechanism of HE CR

KM3NeT-ORCA ANTARES KM3NeT-ARCA

+ oceanography, biology, bioacoustics, seismology,…

Neutrinos and multi-messenger astronomy





Neutrinos: neutral, stable, weakly interacting

not absorbed by background light/CMB ➔ access to cosmological distances
not absorbed by matter ➔ access to dense environments
not deviated by magnetic fields ➔ astronomy over full energy range
three flavours ➔ additional information on source

‘Smoking gun’ signature for hadronic processes

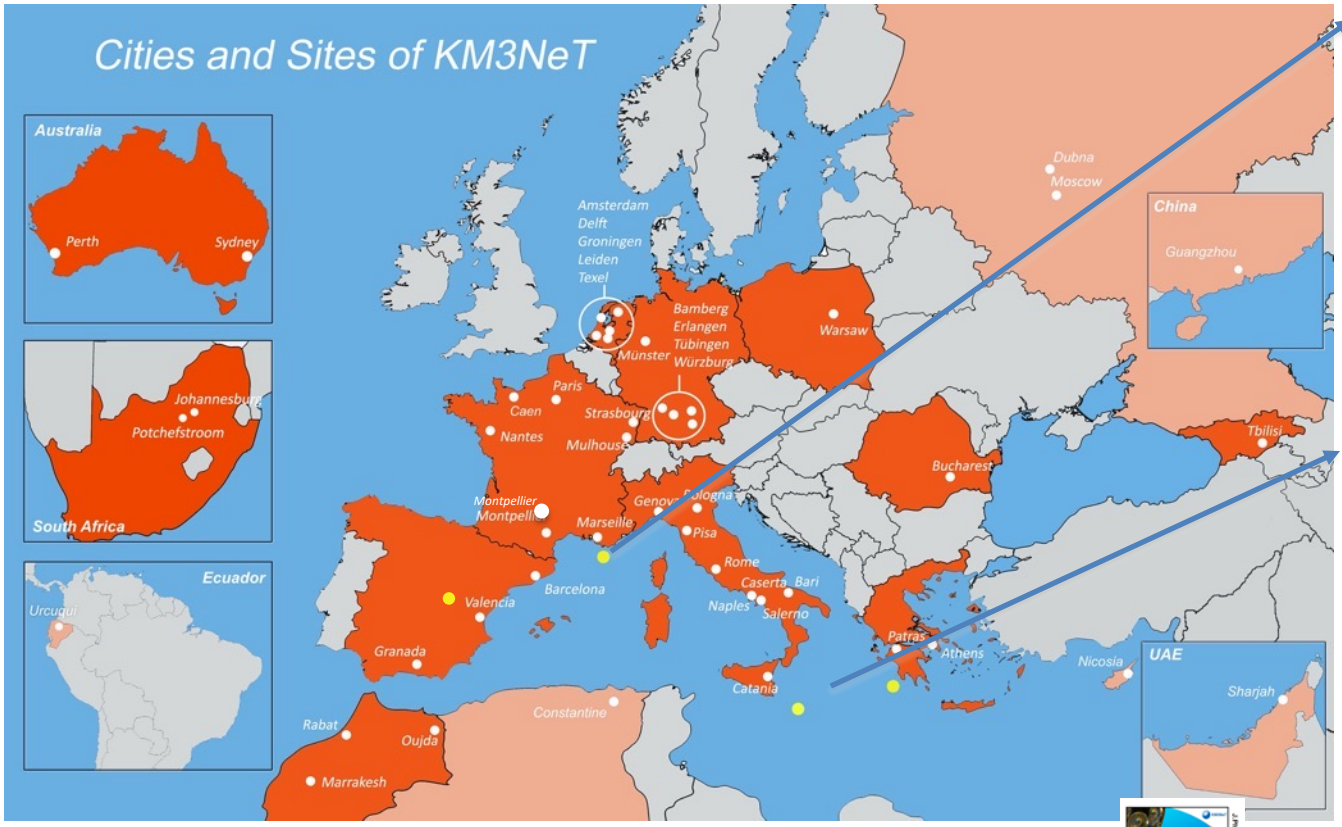
Correlated in time/direction with electromagnetic and gravitational waves

KM3NeT

Multi-site, deep-sea infrastructure

Selected for ESFRI roadmap

Single collaboration, Single technology



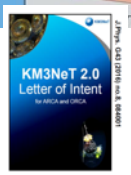
Oscillation **R**esearch with **C**osmics In the **A**byss

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

[KM3NeT 2.0: Letter of Intent](http://dx.doi.org/10.1088/0954-3899/43/8/084001)

http://dx.doi.org/10.1088/0954-3899/43/8/084001

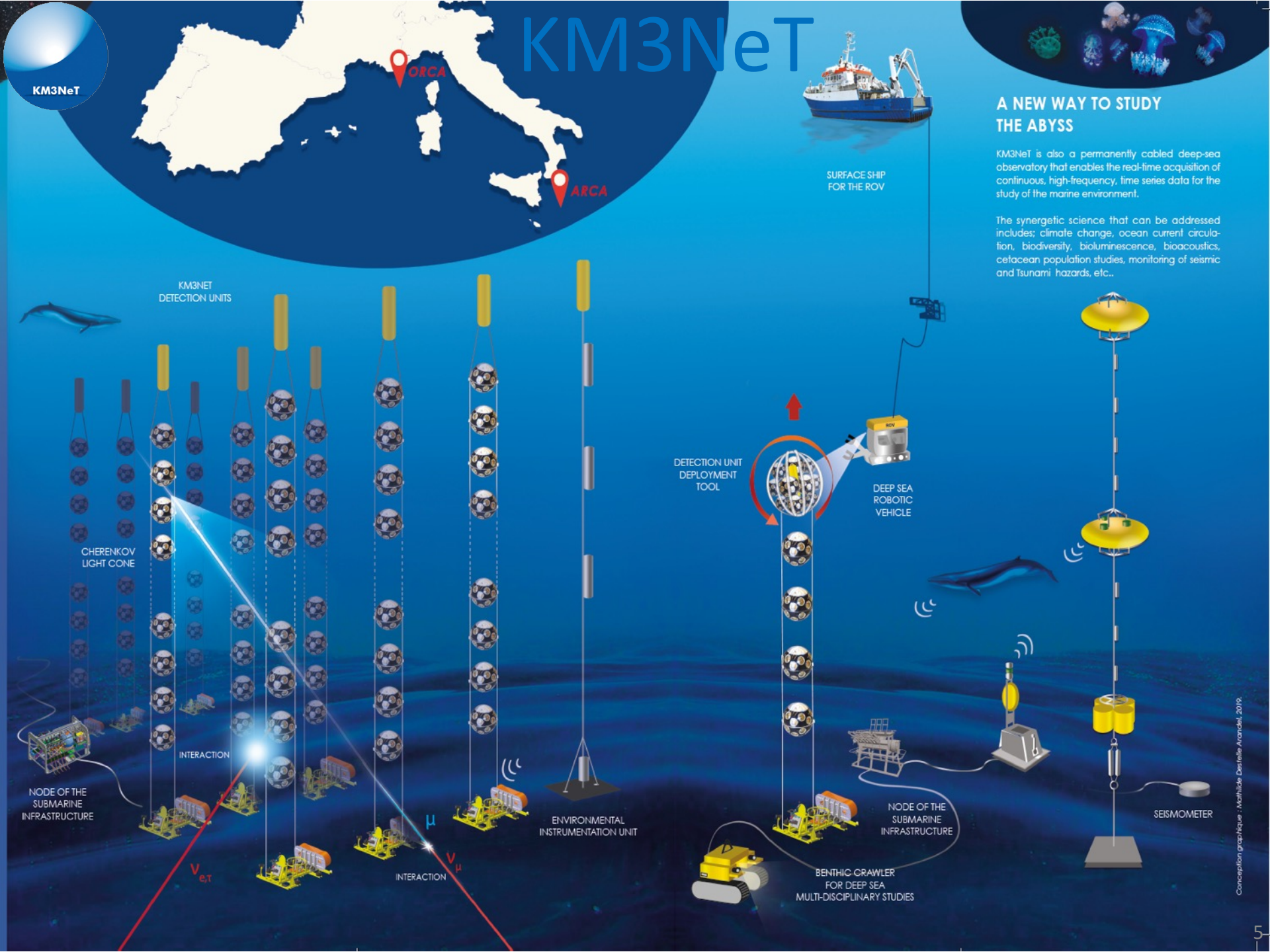
J. Phys. G: Nucl. Part. Phys. 43 (2016) 084001



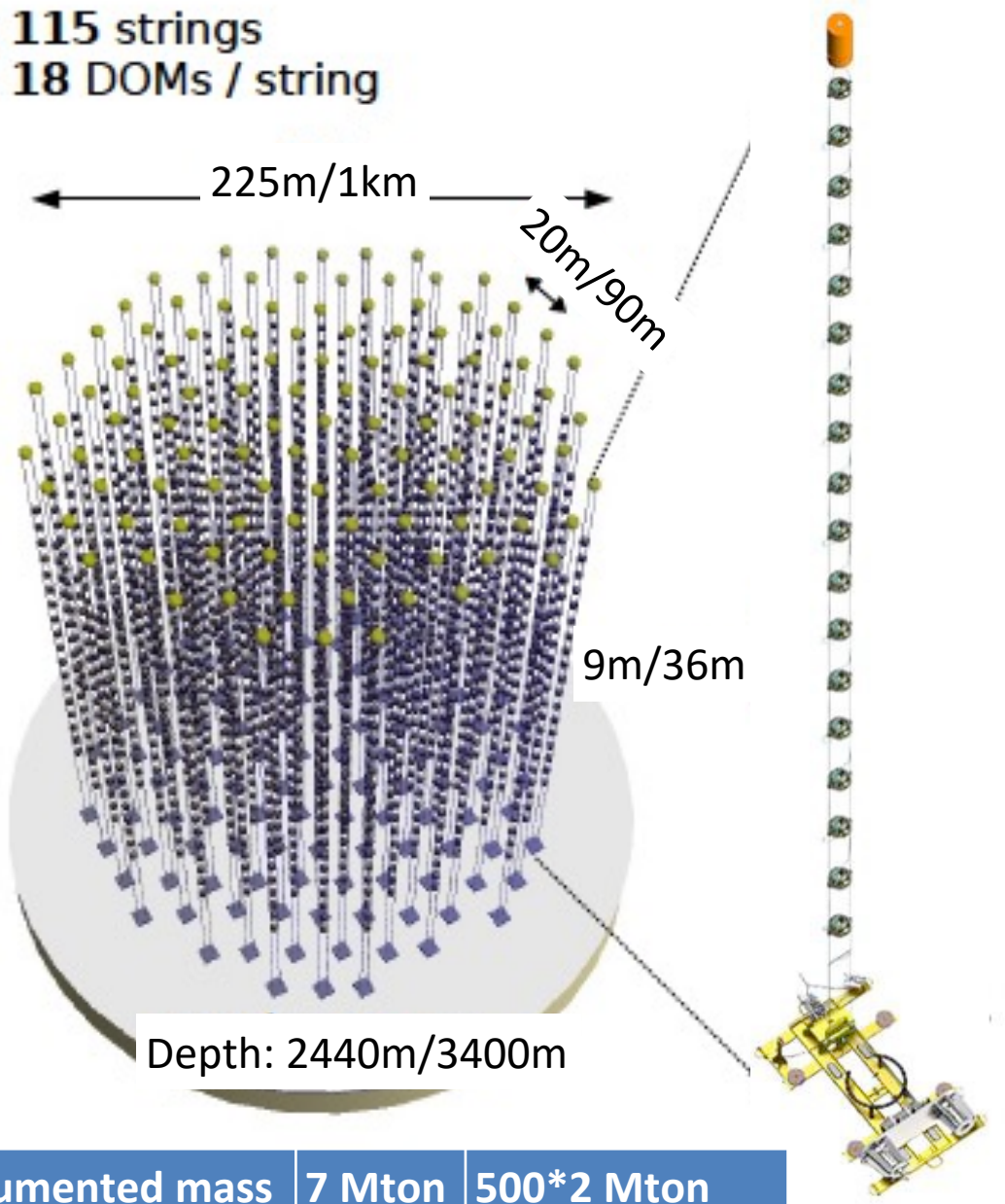
Connection nodes of

european multidisciplinary seafloor & water column observatory

emso


KM3NeT
ORCA
ARCA
SURFACE SHIP FOR THE ROV
A NEW WAY TO STUDY THE ABYSS
KM3NeT is also a permanently cabled deep-sea observatory that enables the real-time acquisition of continuous, high-frequency, time series data for the study of the marine environment.
The synergetic science that can be addressed includes; climate change, ocean current circulation, biodiversity, bioluminescence, bioacoustics, cetacean population studies, monitoring of seismic and Tsunami hazards, etc..
KM3NET DETECTION UNITS
CHERENKOV LIGHT CONE
INTERACTION
NODE OF THE SUBMARINE INFRASTRUCTURE
ENVIRONMENTAL INSTRUMENTATION UNIT
INTERACTION
DETECTION UNIT DEPLOYMENT TOOL
DEEP SEA ROBOTIC VEHICLE
NODE OF THE SUBMARINE INFRASTRUCTURE
BENTHIC CRAWLER FOR DEEP SEA MULTI-DISCIPLINARY STUDIES
SEISMOMETER
Conception graphique : Mathilde Desrelle Arandel, 2019.

KM3NeT building block



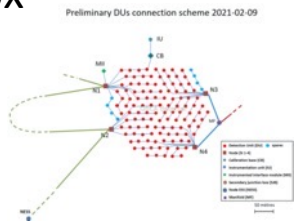
- 31 x 3” PMTs
- All data to shore: Gbit/s optical fibre
- White Rabbit time synchronisation
- LED flasher & acoustic piezo
- Tiltmeter/compass
- Low drag

Instrumented mass	**7 Mton**	**500*2 Mton**

Seafloor infrastructures

ORCA
2nd junction box
Oct 2020

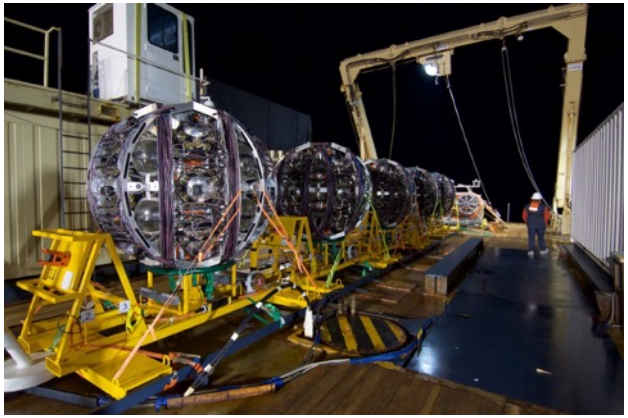
ORCA
(France)



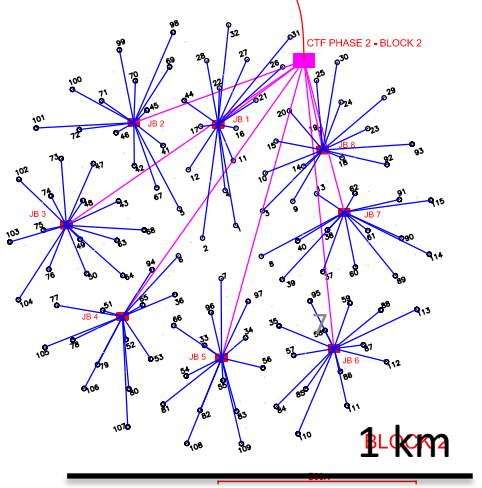
200 m

ARCA
(Italy)

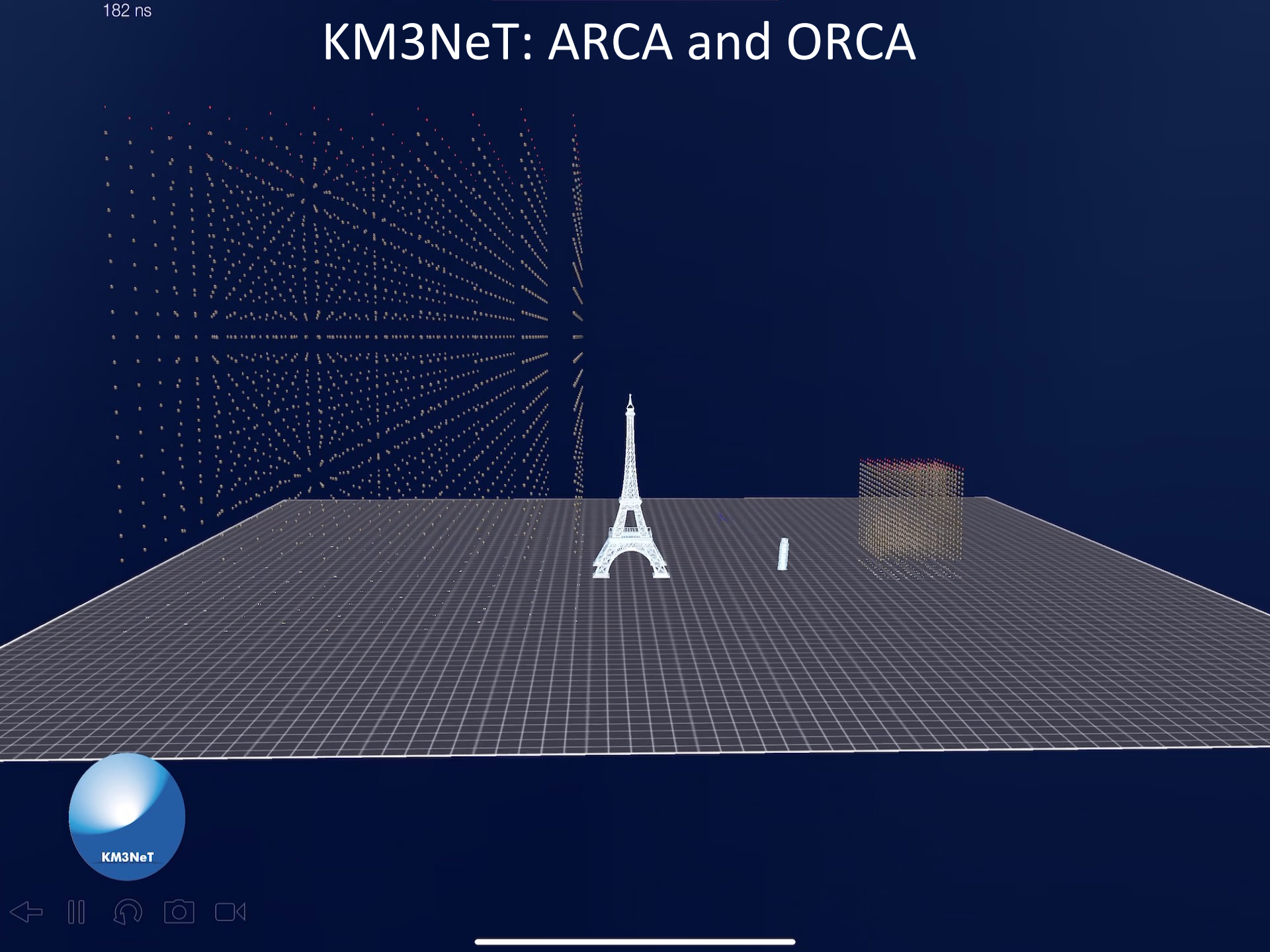
ARCA
2nd Cable
Nov 2020



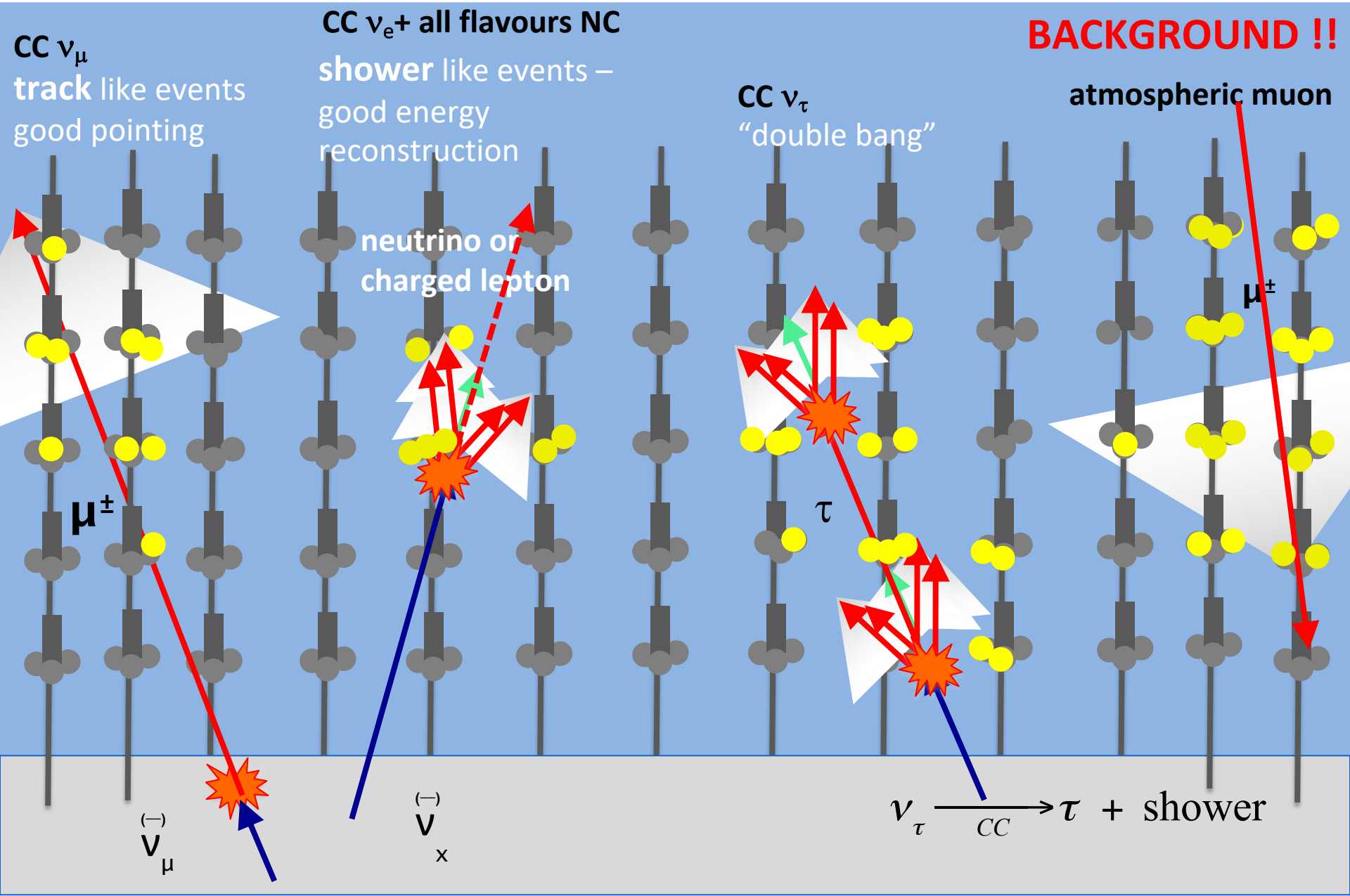
ARCA
junction box
+5 detection units
April 2021



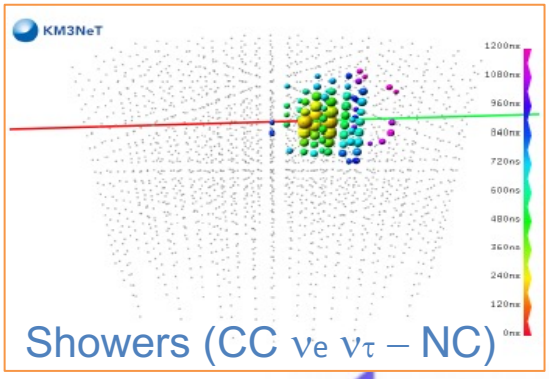
1 km

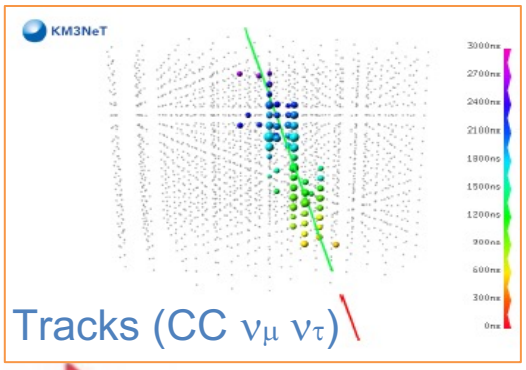

182 ns
KM3NeT: ARCA and ORCA
KM3NeT

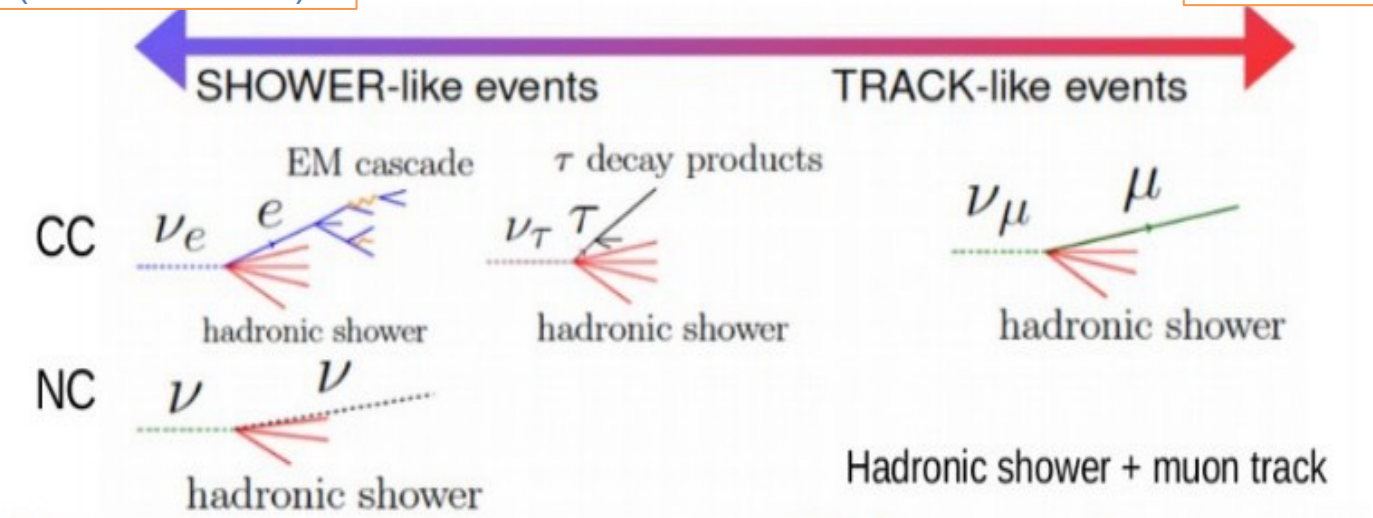
Event Topologies



Resolutions







Angular resolution 10°/1°
at 100 TeV for Ice/water

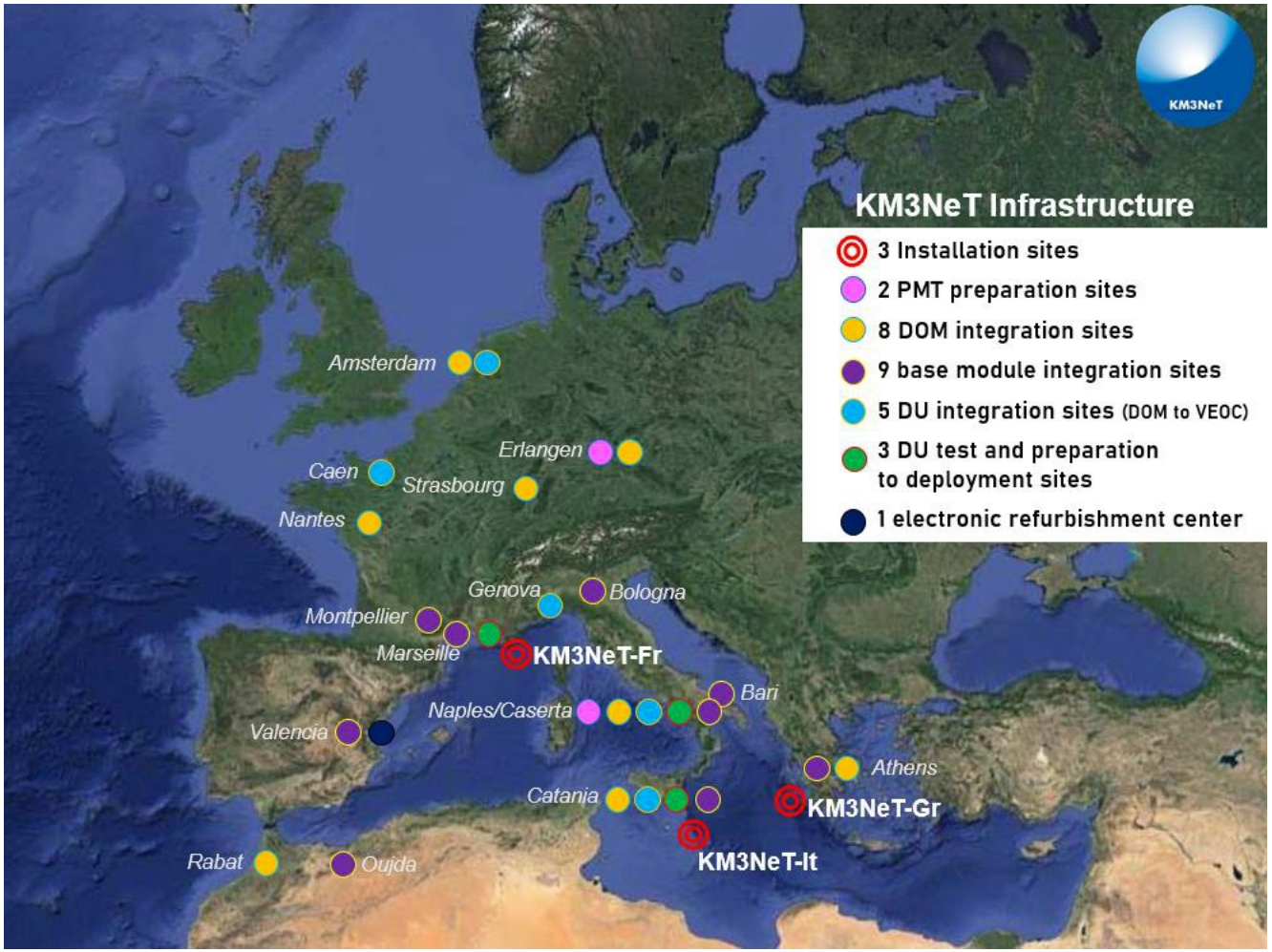
Energy resolution ~ 5%

Angular resolution 0.5°/0.1°
at 100 TeV for Ice/water

Energy resolution ~ 200-300%
(if contained: 25%)

Precision multi-flavour astronomy with water based telescopes

Detector construction all around Europe



DOMs
- 8 integration sites
- 860 produced
- 105 currently on bench

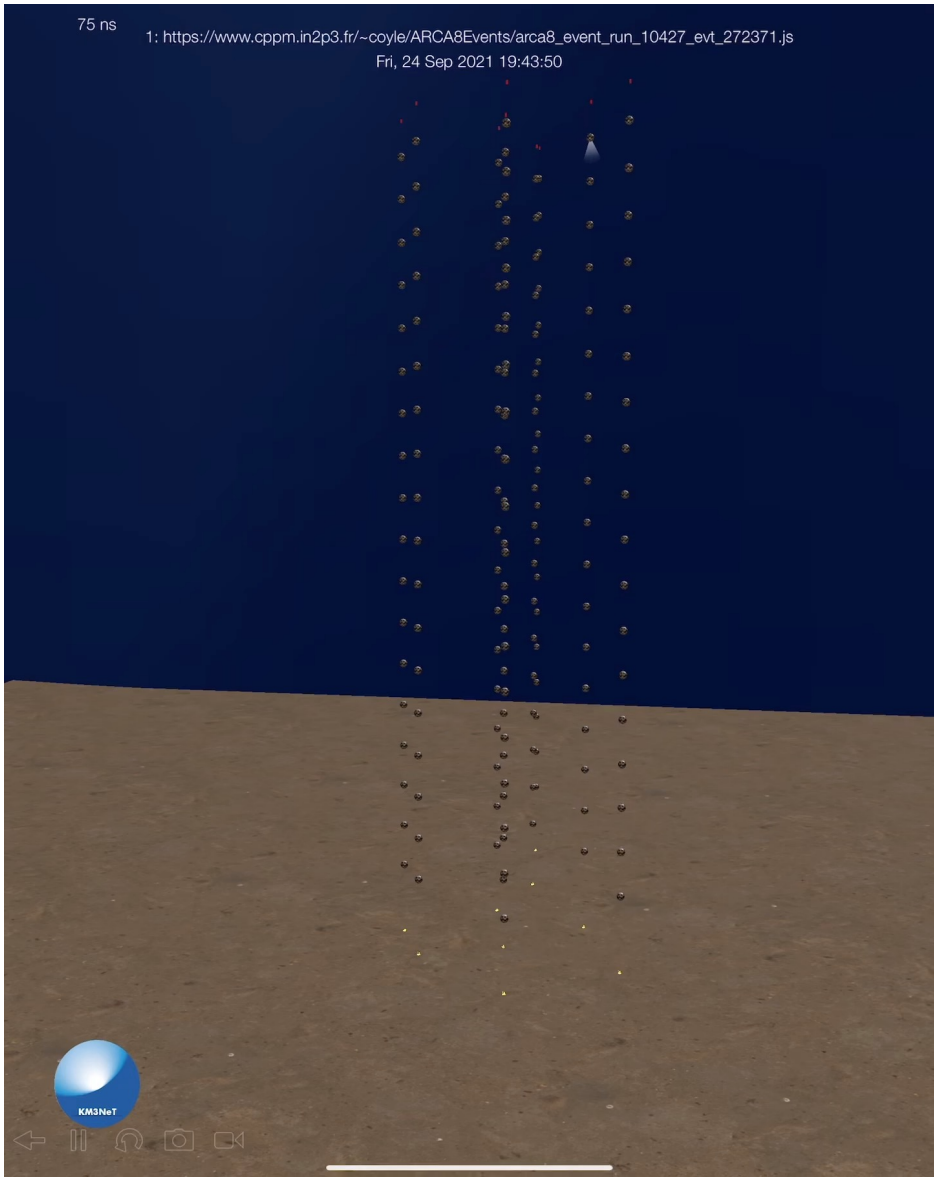
Base Modules
- 9 integration sites
- 45 BM produced
- 5 currently on bench

Detection Units
- 6 integration sites
- 33 DUs produced
- 8 currently on bench
- 19 deployed

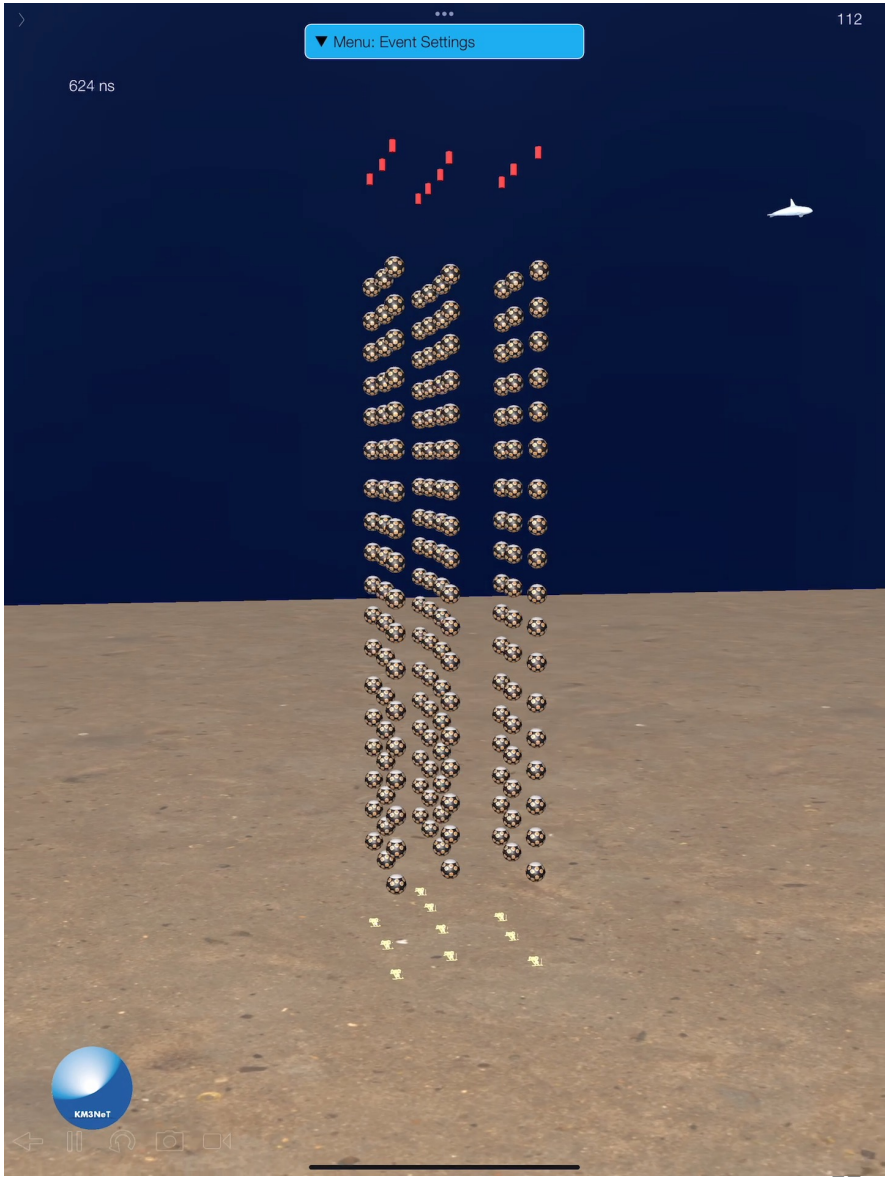
Despite pandemic big efforts are on going in the detector construction

18 KM3NeT detection units operational

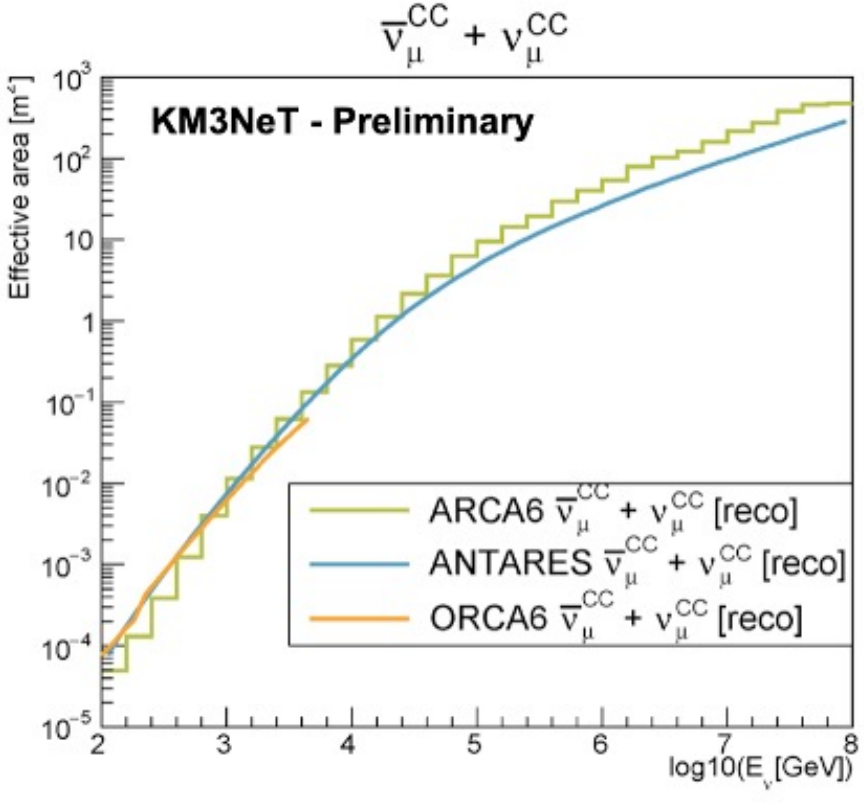
ARCA8

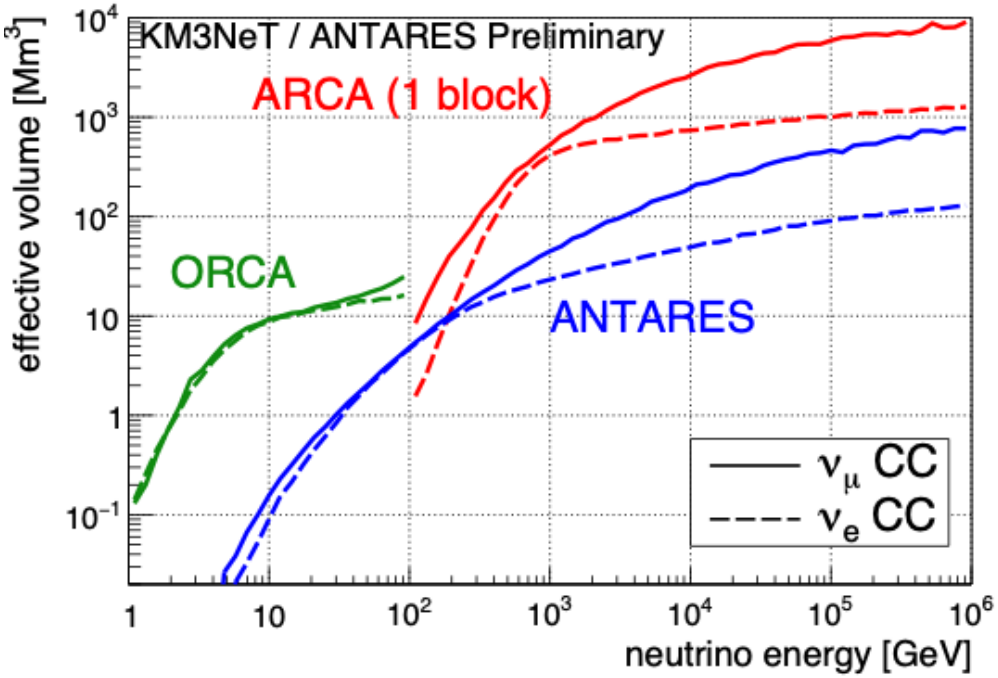


ORCA10



Effective areas: KM3NeT vs ANTARES

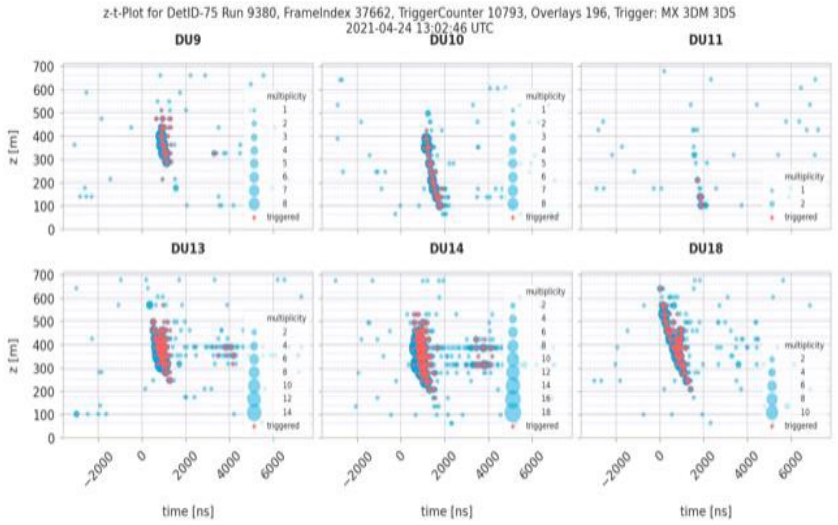


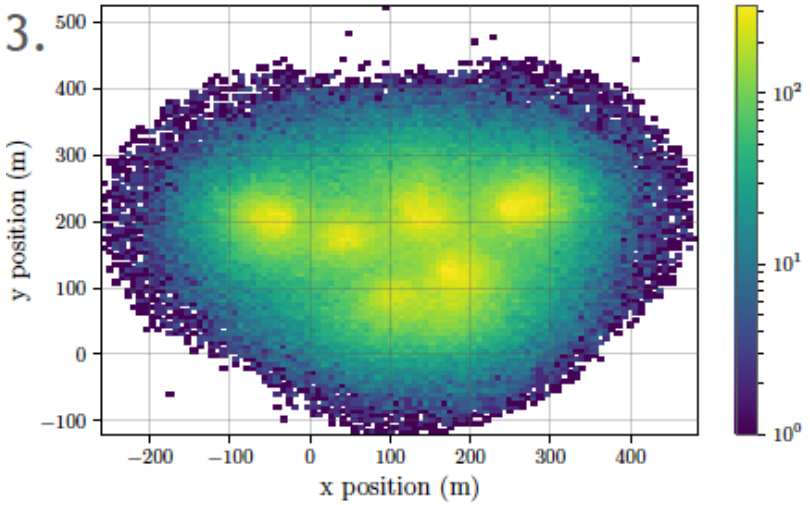


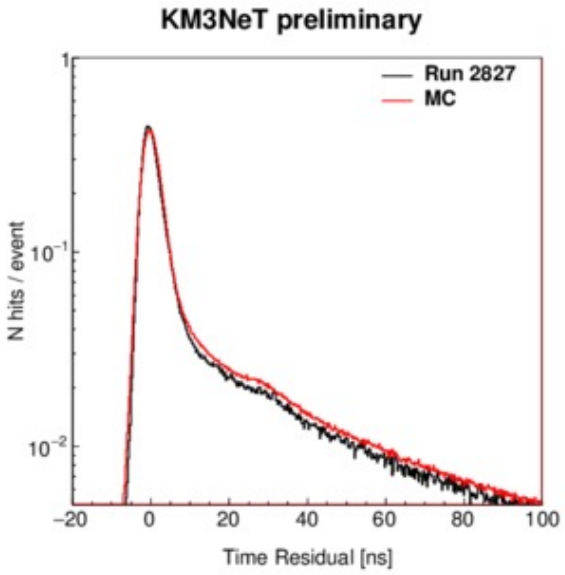
ARCA6+ORCA6 bit better than ANTARES

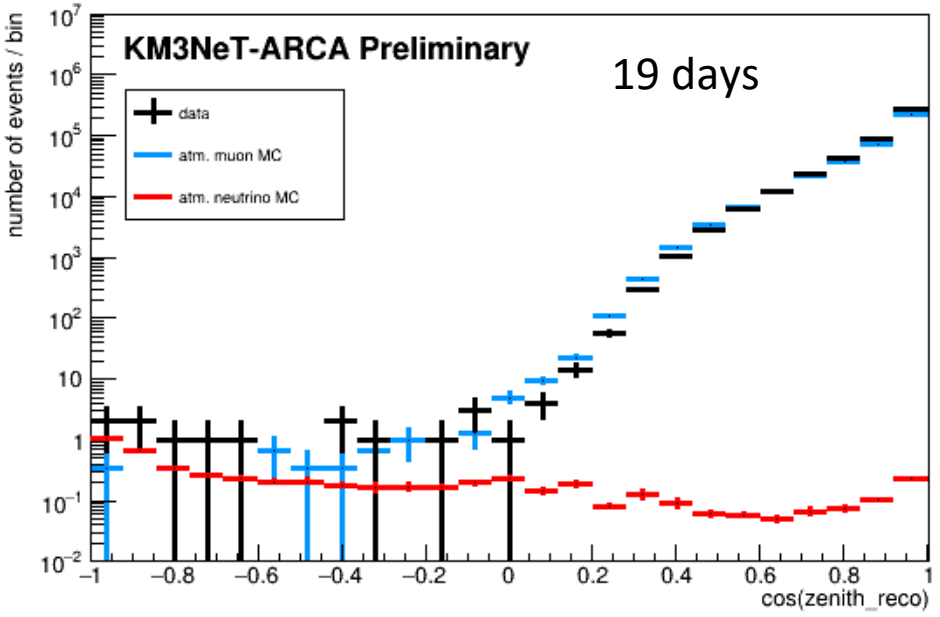
Completion of ORCA115 array in 2026 and ARCA230 in 2027

ARCA6 data

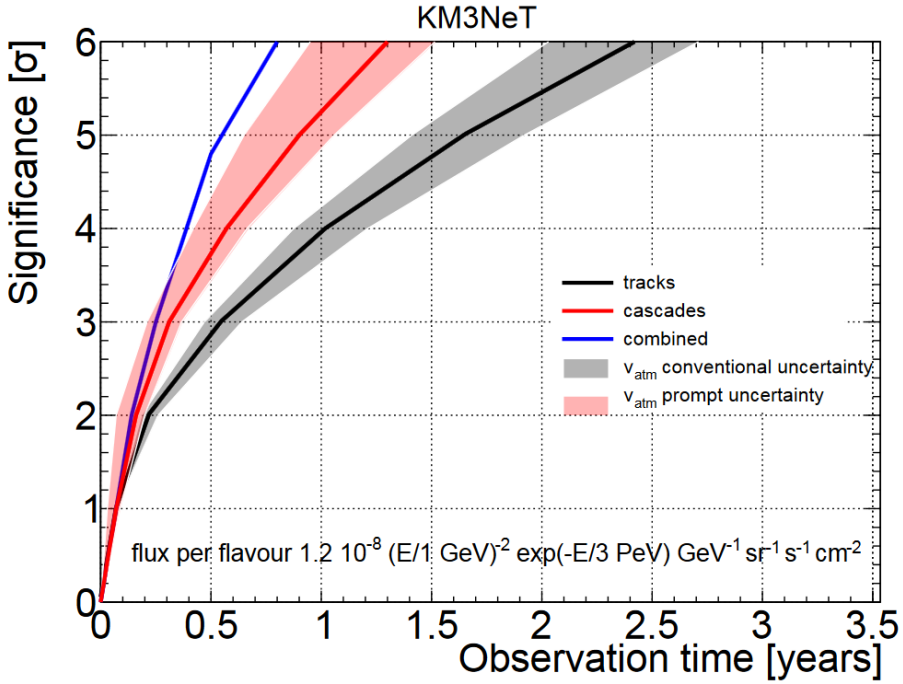

z-t-Plot for DetID-75 Run 9380, FrameIndex 37662, TriggerCounter 10793, Overlays 196, Trigger: MX 3DM 3DS
2021-04-24 13:02:46 UTC
DU9
DU10
DU11
DU13
DU14
DU18
z [m]
time [ns]
multiplicity
triggered

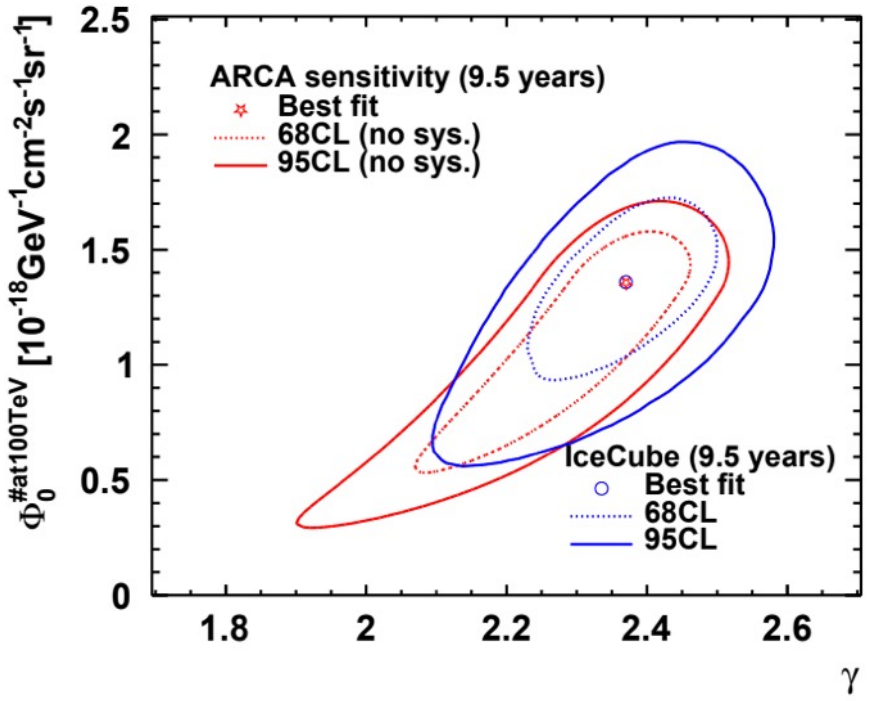

3.
y position (m)
x position (m)


KM3NeT preliminary
Run 2827
MC
N hits / event
Time Residual [ns]


KM3NeT-ARCA Preliminary
19 days
data
atm. muon MC
atm. neutrino MC
number of events / bin
cos(zenith_reco)

KM3NeT diffuse cosmic flux

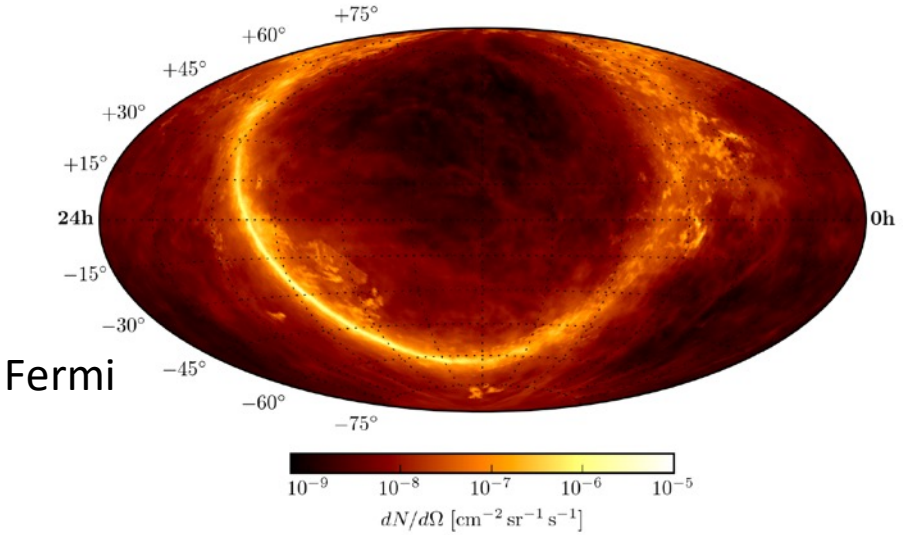




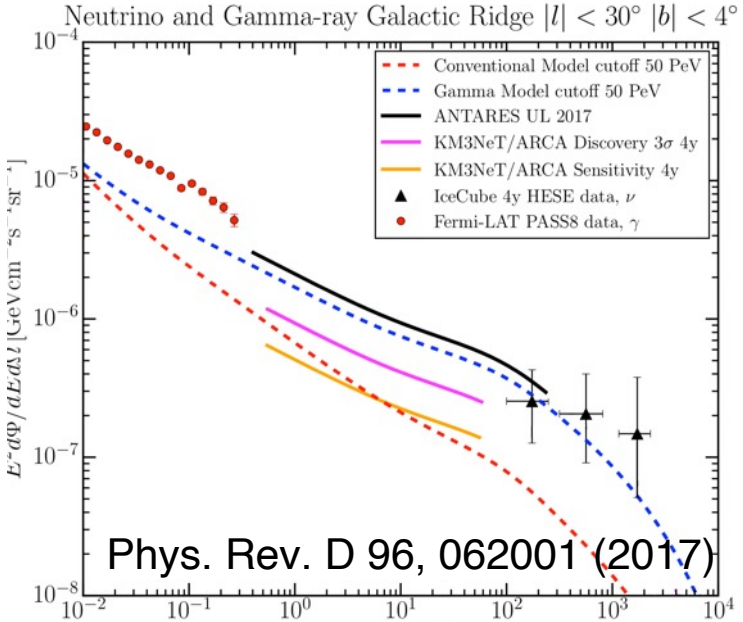
5σ in ~ 0.5 year for the full detector (230 DUs)

5σ ~ 1 year for one block detector (115 DUs)

Galactic plane



Fermi



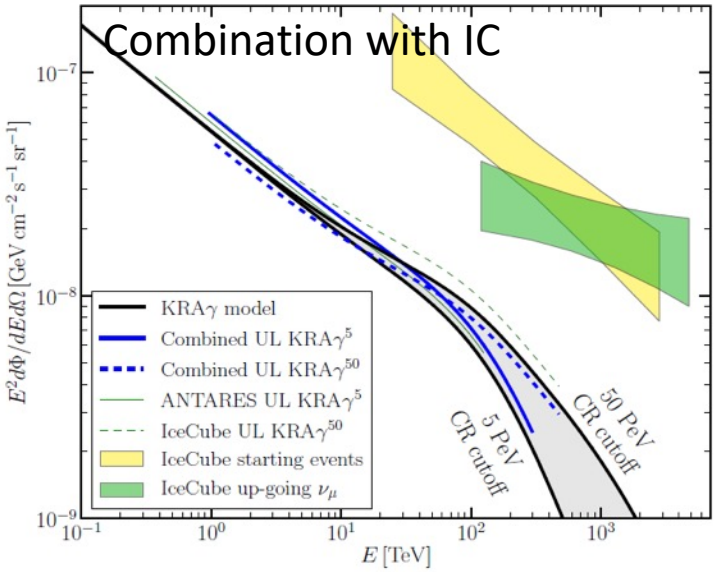
Guaranteed galactic neutrinos from CR interactions with matter

Analysis uses full model morphology & spectrum – tracks and cascades

ANTARES Limit is a factor 1.2 above the 'KRAγ' model.

ANTARES updated analysis soon

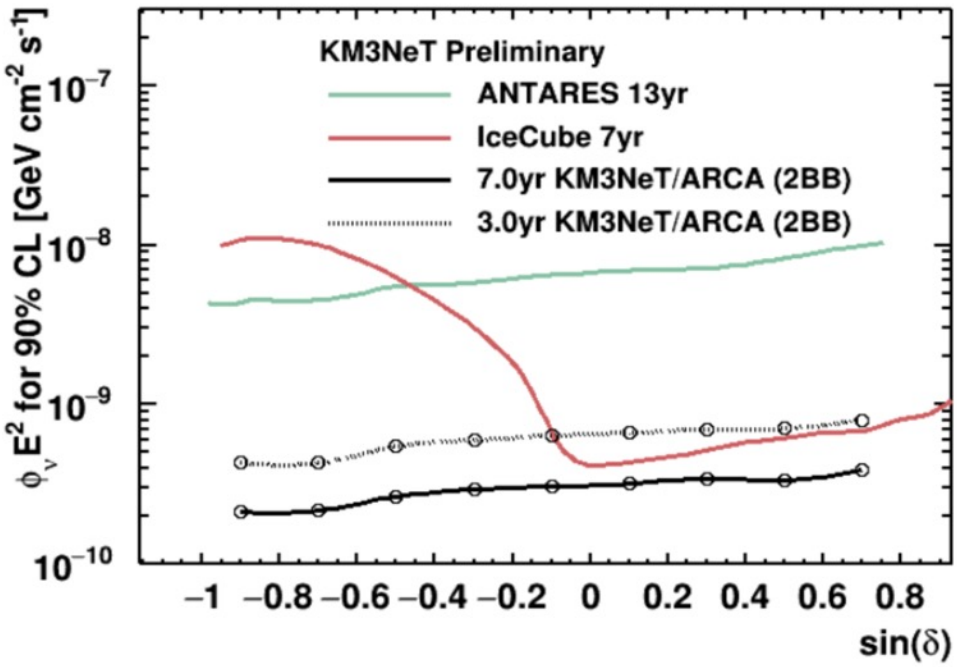
KM3NeT sensitivity very promising



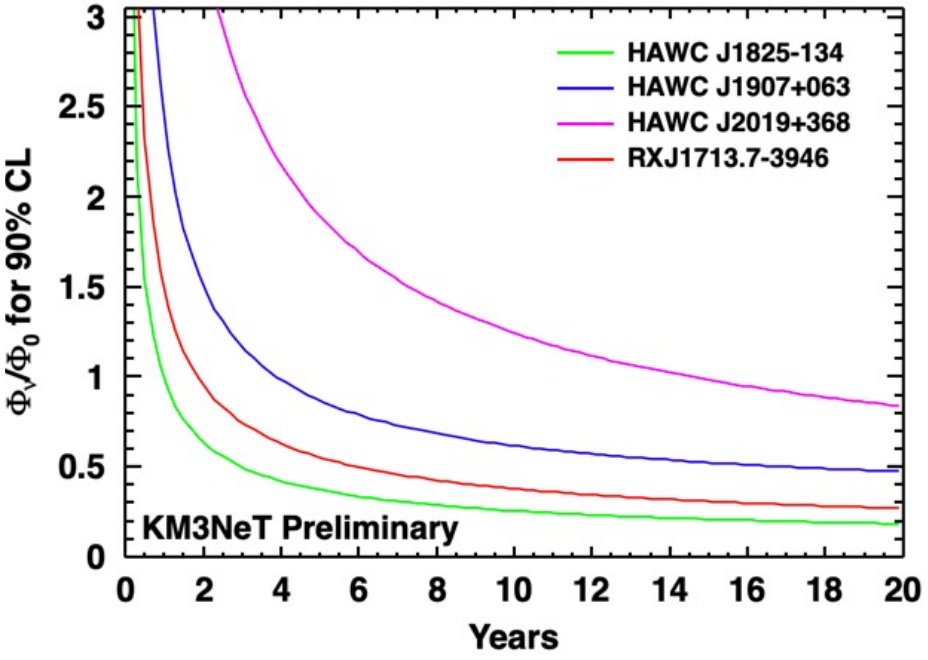
ApJL 868, L20 (2018)

KM3NeT: sources

Point sources

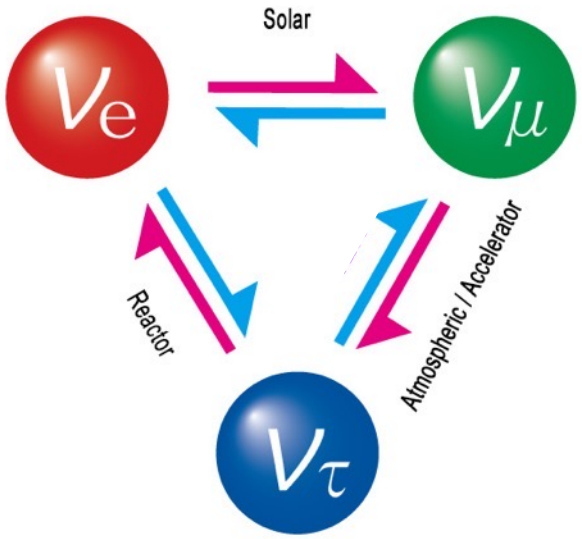


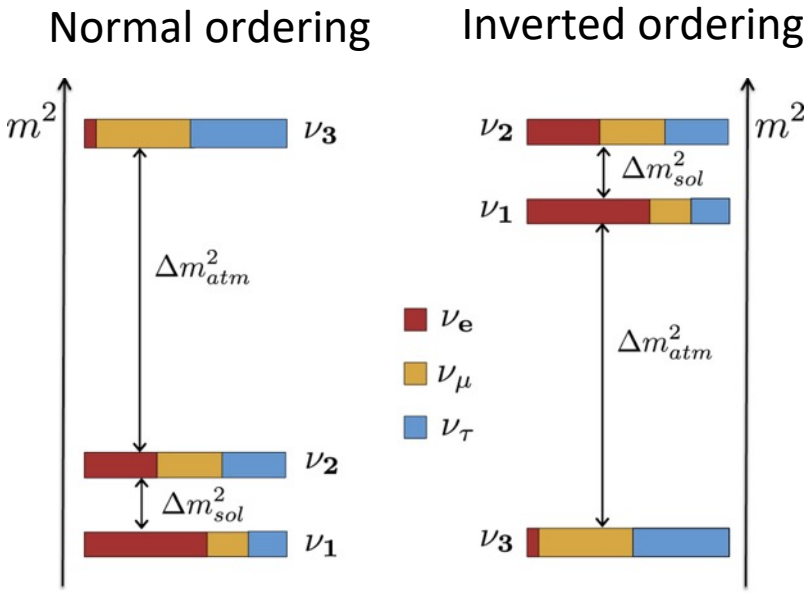
Extended sources

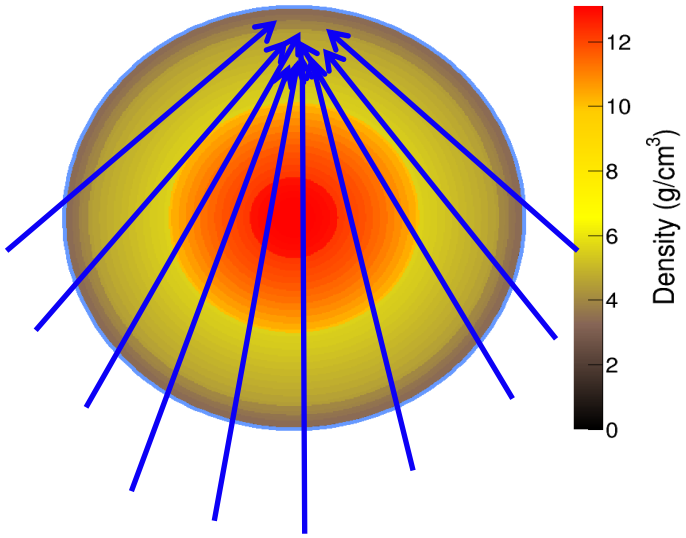


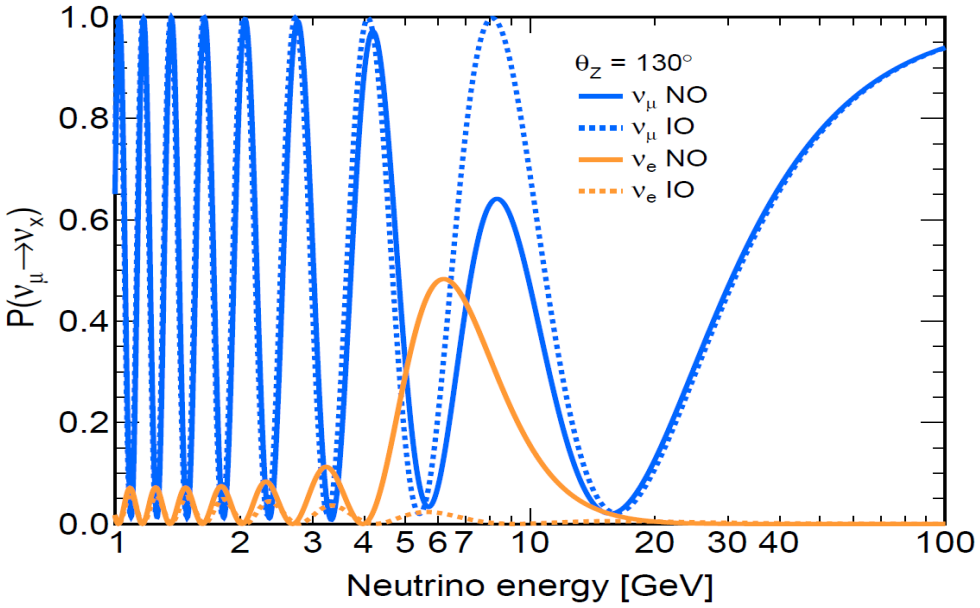
Source	Decl, RA [°]	Ext [°]
RXJ 713.7-3946	-39.77, 258.8	0.6 (disk)
HAWC J1825-134	-13.37, 276.4	0.53 (Gauss)
HAWC J2019+368	36.76, 304.92	0.356 (Gauss)
HAWC J1907+063	6.32, 286.91	0.67 (Gauss)

neutrino oscillations with atmospheric neutrinos



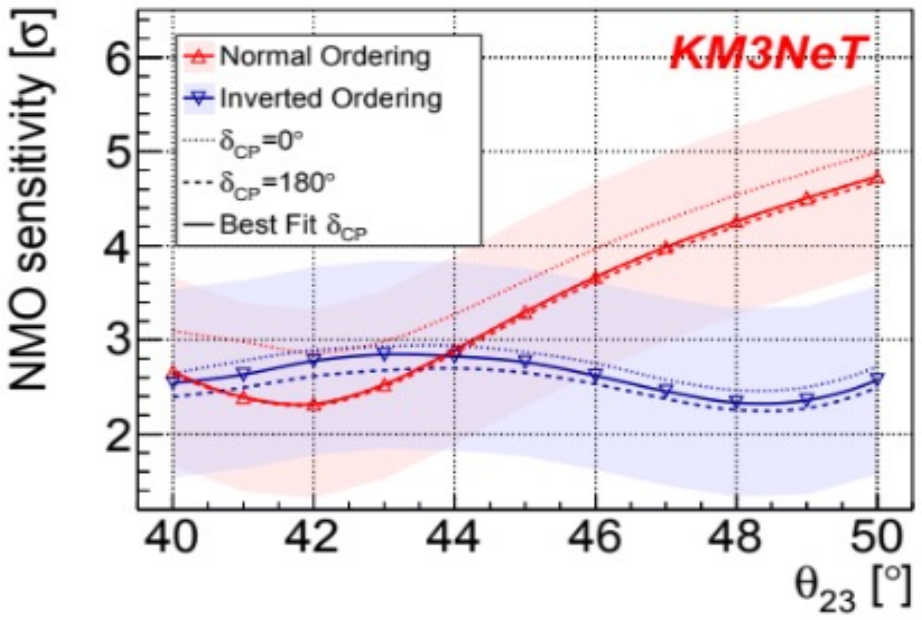






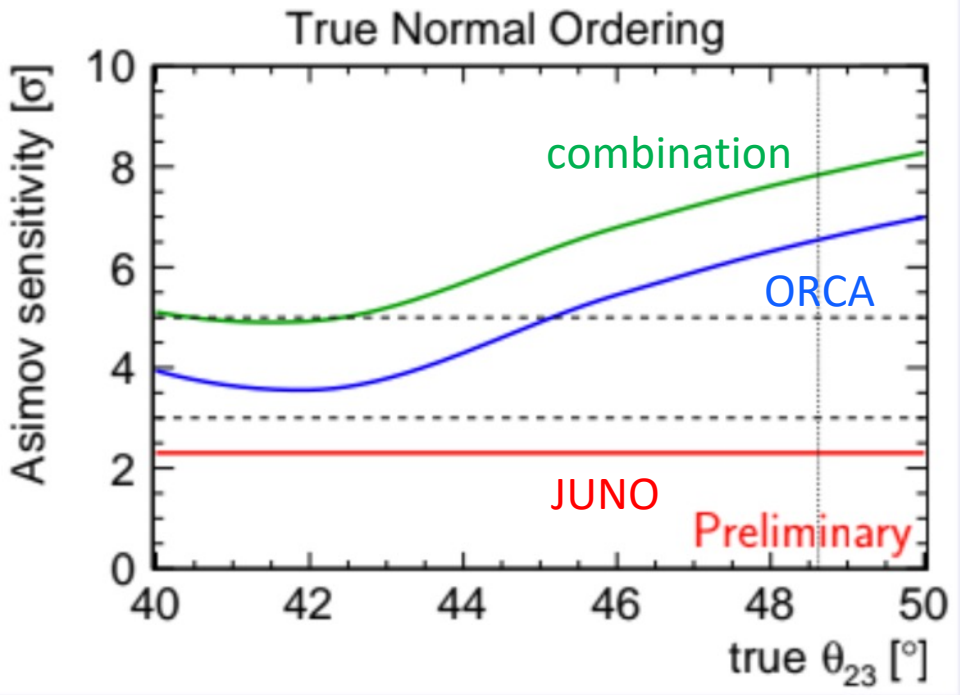
ORCA115: neutrino mass ordering

3 years



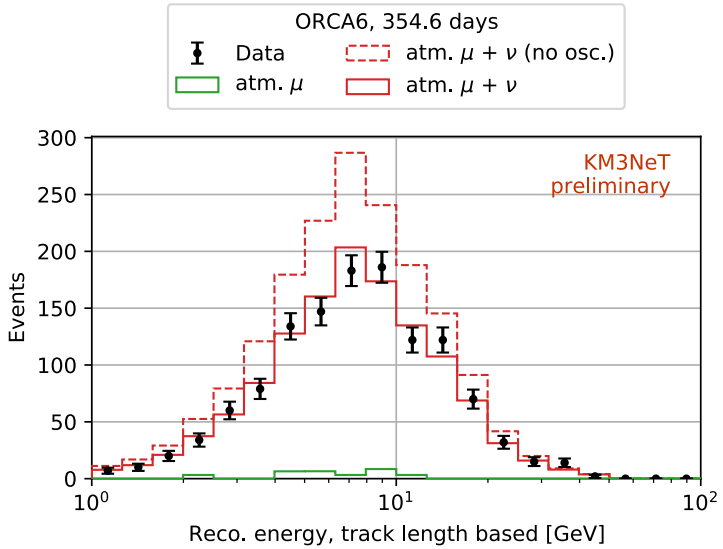
2.5-5σ determination of Neutrino Mass Ordering possible in 3 years

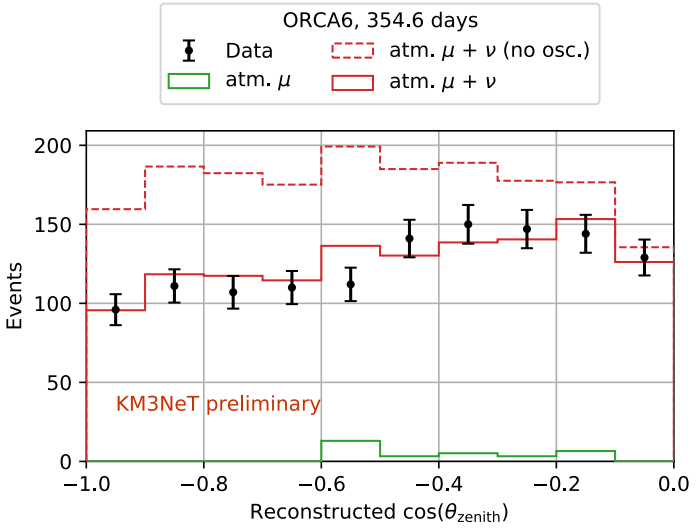
6 yrs & combination with JUNO

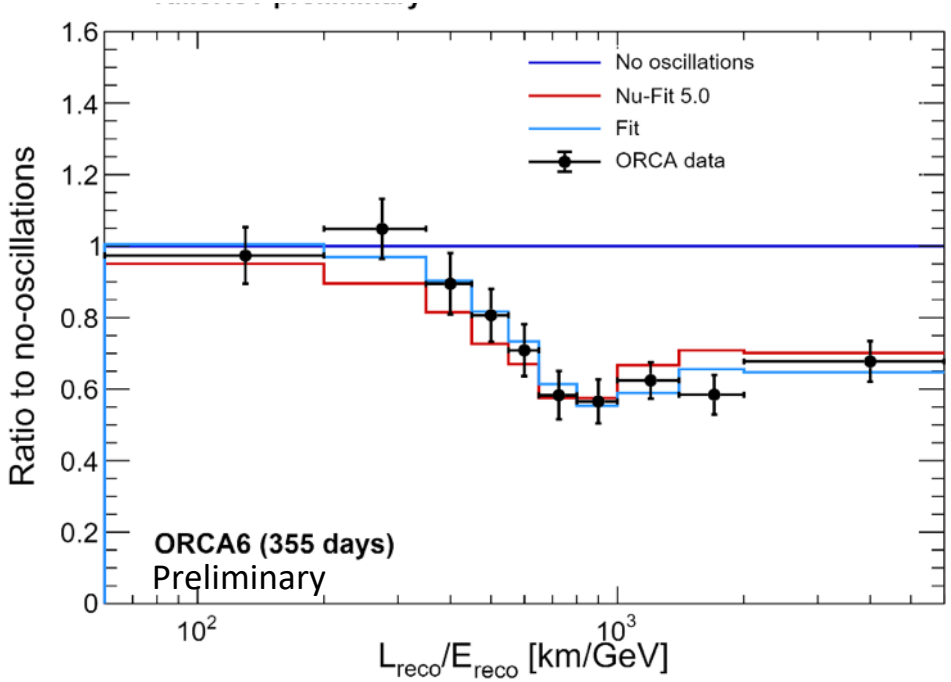


Combination power relies on tension between best-fit of Δm^2_{31} in "wrong ordering" between JUNO and ORCA

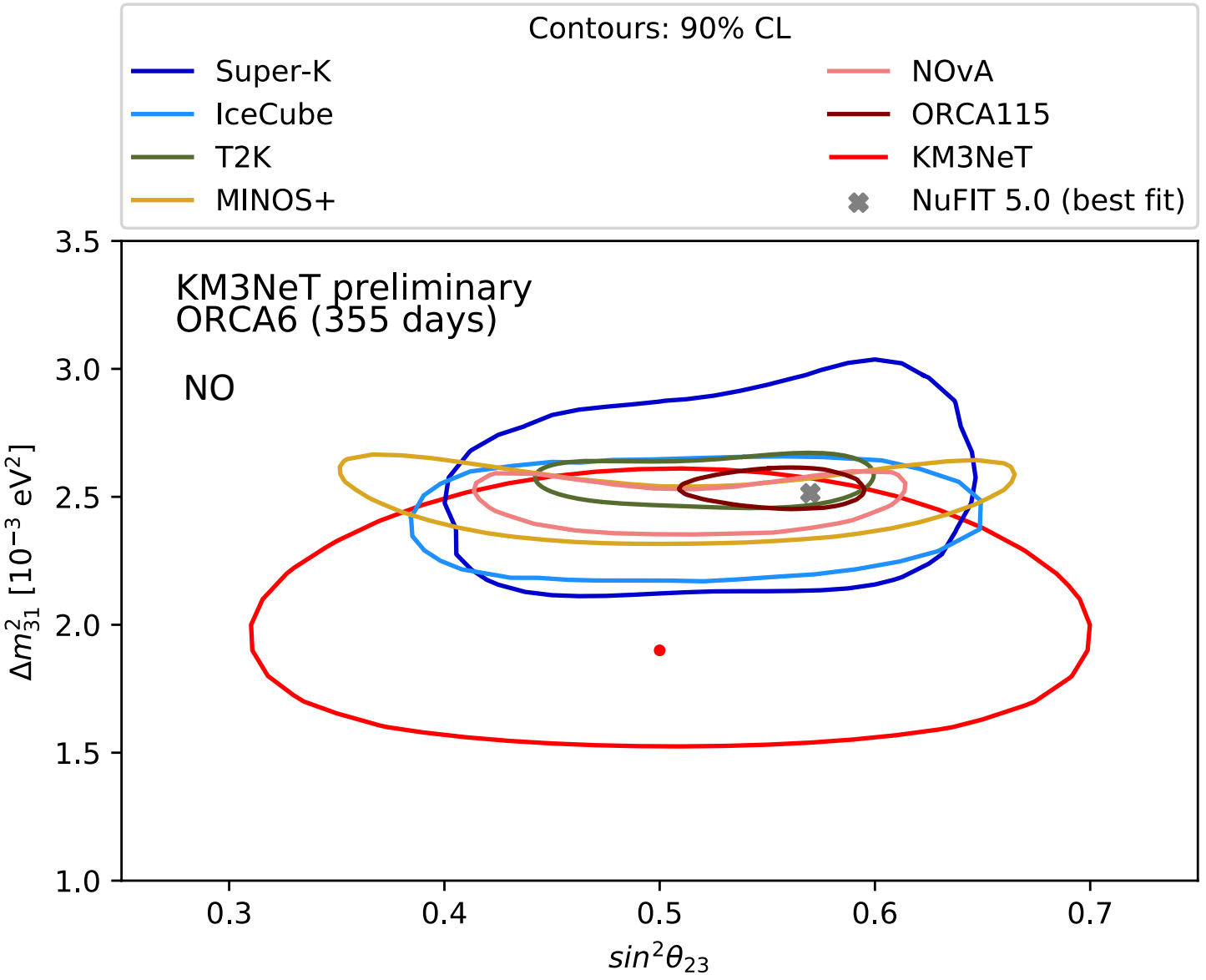
ORCA6 neutrino oscillations (tracks)







ORCA115: neutrino oscillations sensitivity (3 years)



ORCA115: NMO compared with the world

Draft SNOWMASS White paper, Denton et al., 2022

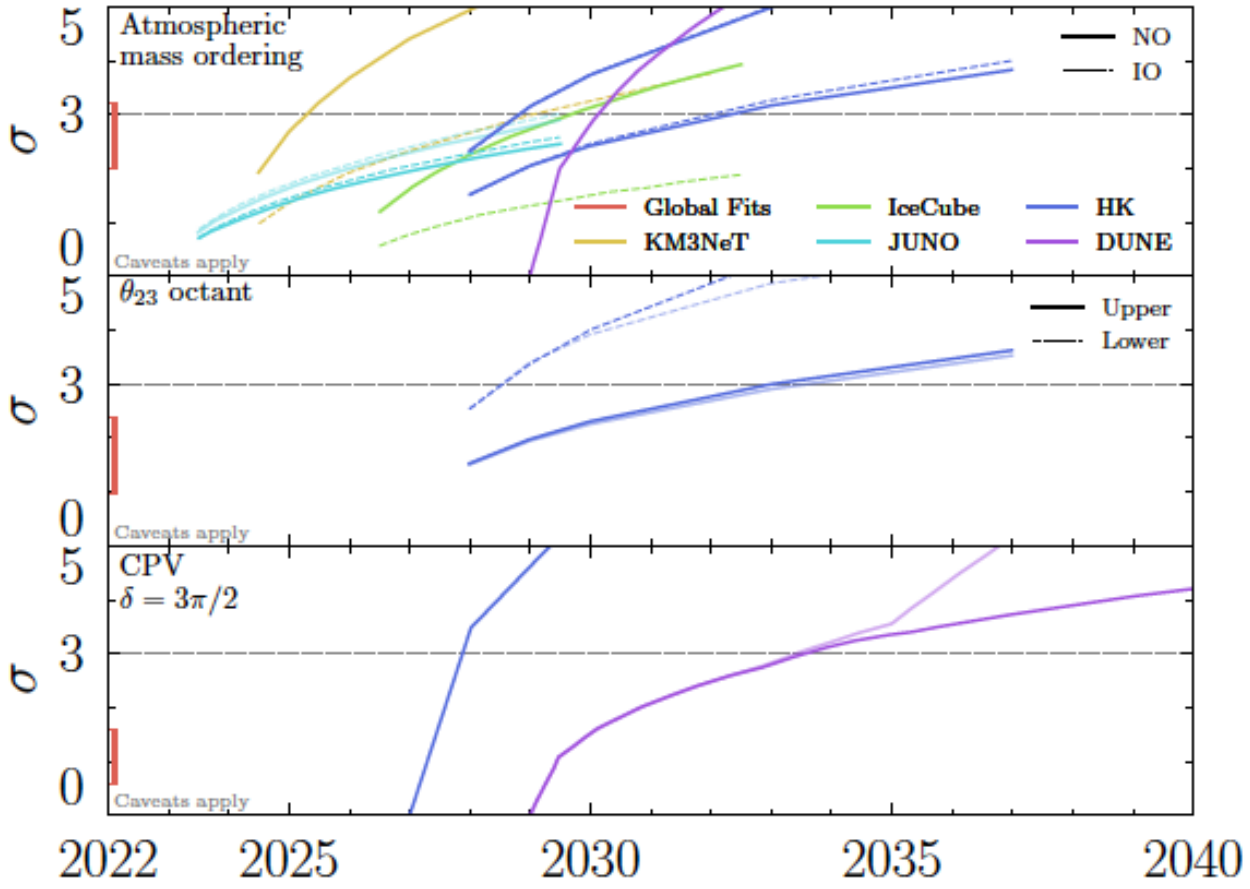
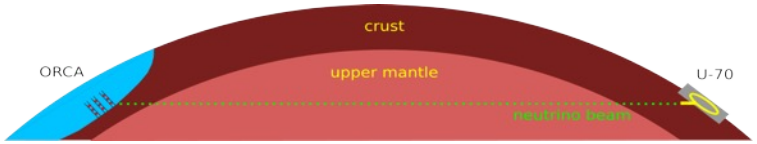


Figure 26: The estimated sensitivities to the three remaining oscillation unknowns based on the latest estimates of sensitivities and starting dates. Many caveats are required, see the text for details. *[Note: DUNE has sensitivity to the octant; future versions will include this curve.]*

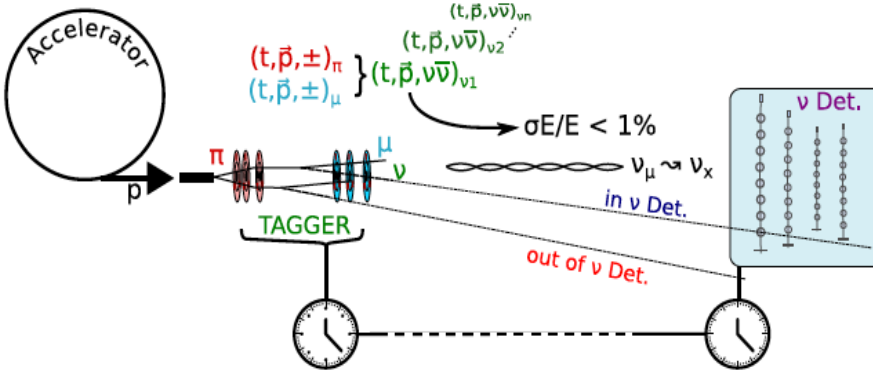
New idea: Tagged Protvino to ORCA

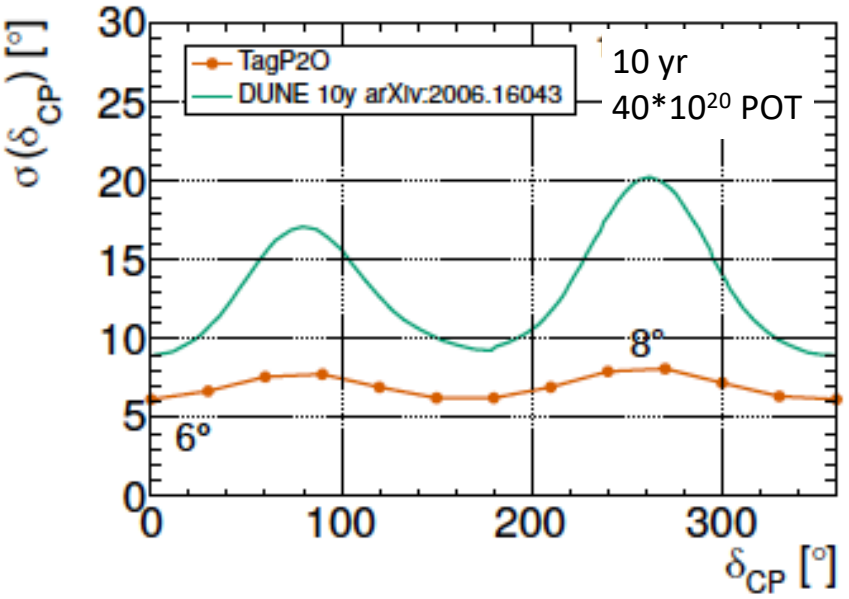
A. V. Akindinov et al.,
"Letter of Interest for a Neutrino Beam from Protvino to KM3NeT/ORCA"
https://arxiv.org/abs/1902.06083



- Neutrino Beam from Protvino to ORCA
- Baseline 2590 km
- First oscillation maximum 5.1 GeV
- Sensitivity to mass hierarchy and CPV
- LoI published: arXiv:1902.06083
- Huge detector -> relax beam power
- New idea - ν tagging at source:

M. Perrin-Terrin
https://arxiv.org/abs/2112.12848





Conclusions and outlook

Water based detectors: angular resolution, multi-flavour astronomy, galactic sources

Intriguing indications of cosmic neutrino sources from ICECUBE/ANTARES associated with radio loud and/or gamma blazar flares

- J0242+1101
- MG3 J225517+2409
- TXS 0506+056

KM3NeT taking data and growing rapidly

First measurement of neutrino oscillation parameters by ORCA6

New ideas in gestation

- Protvino to ORCA (P2O)
- Acoustic detection of UHE neutrinos