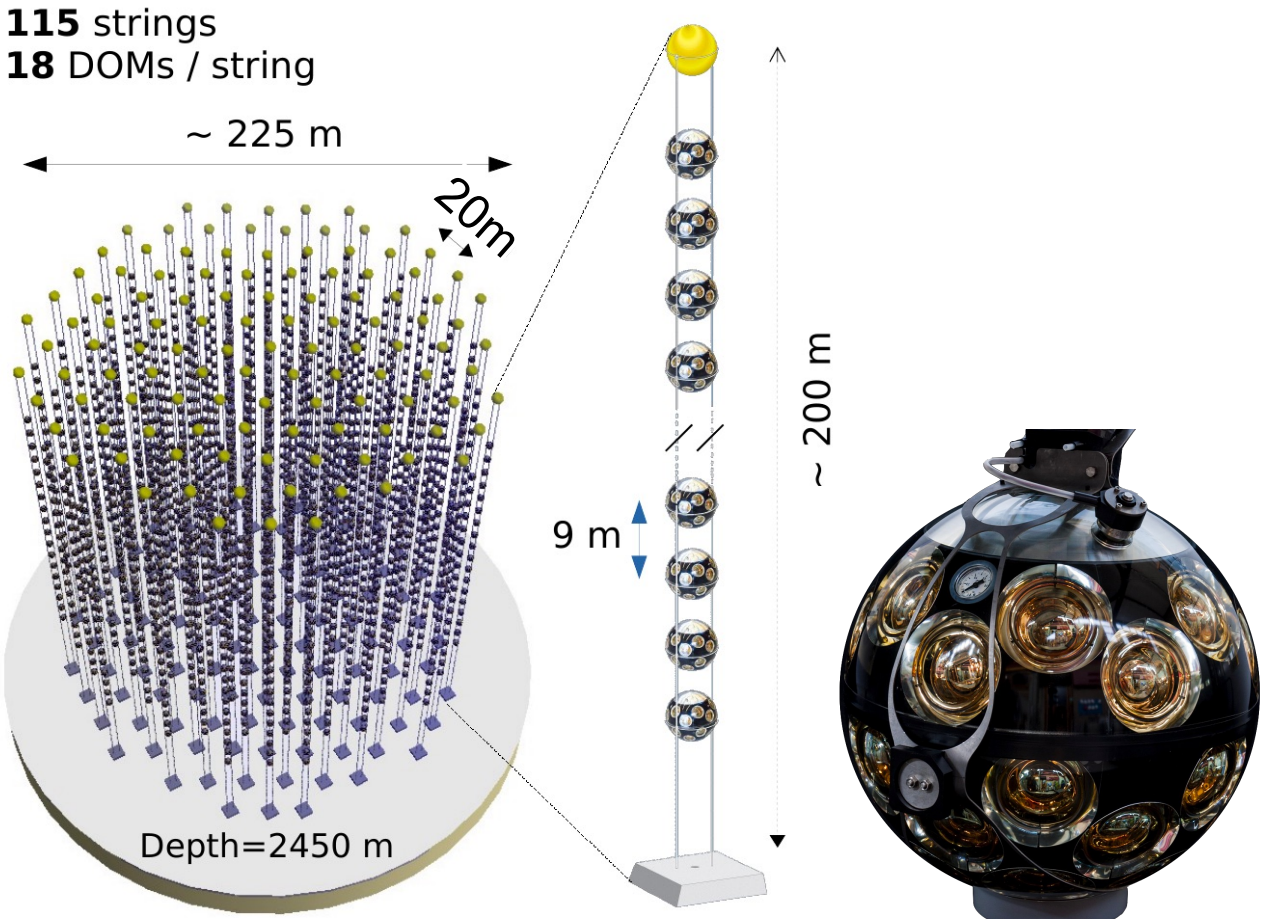
Oscillation research with KM3NeT/ORCA

Lukas Maderer on behalf of the
KM3NeT collaboration

IPA, Vienna, September 8th 2022

KM3NeT/ORCA

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



Digital **O**ptical **M**odule

The detector:

- 115 strings
  Horizontal spacing 20m
- 18 Optical modules per string
  Vertical spacing 9m
- 31 PMTs per optical module
  360° coverage
- 7 Mton instrumented volume

Current status:

- 6 strings since February 2020
- 11 strings since June 2022
- 10 (9) taking data

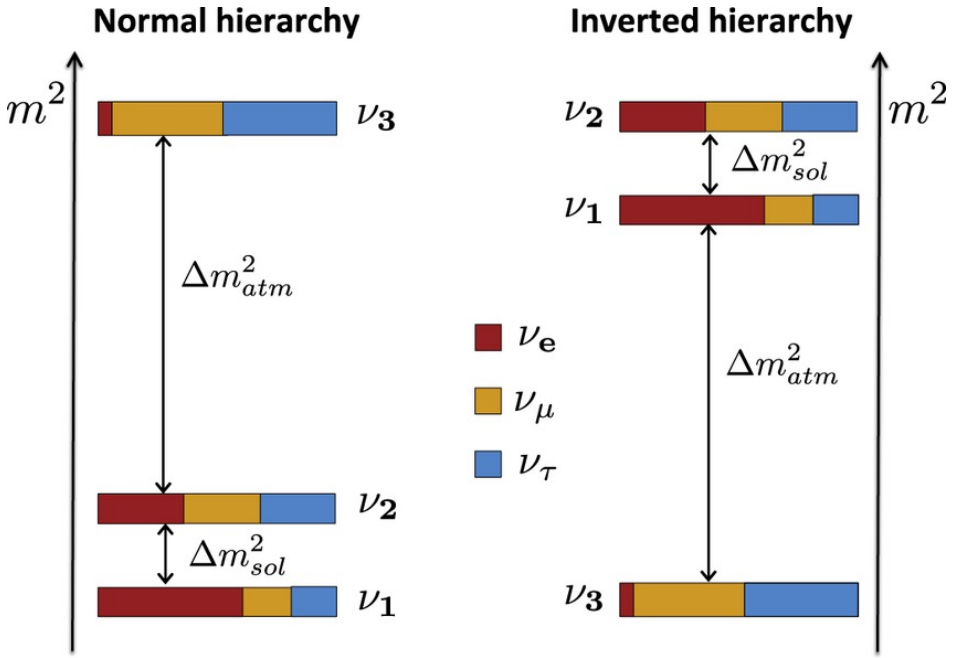
Neutrino Mass Hierarchy

- Oscillation length for $|\Delta m^2_{\mathrm{atm}}| \simeq 2.3\times10^{-3}\,\mathrm{eV}^2 \rightarrow \frac{\mathrm{L}}{\mathrm{E}} \sim 10^3\,\mathrm{km\ GeV}^{-1}$
- MSW resonance: $\sin^2 2\theta^{\mathrm{M}} = \dfrac{\sin^2 2\theta}{\sin^2 2\theta + \left(\cos 2\theta \mp \frac{2\sqrt{2}EG_F n_e}{\Delta m^2}\right)^2}$

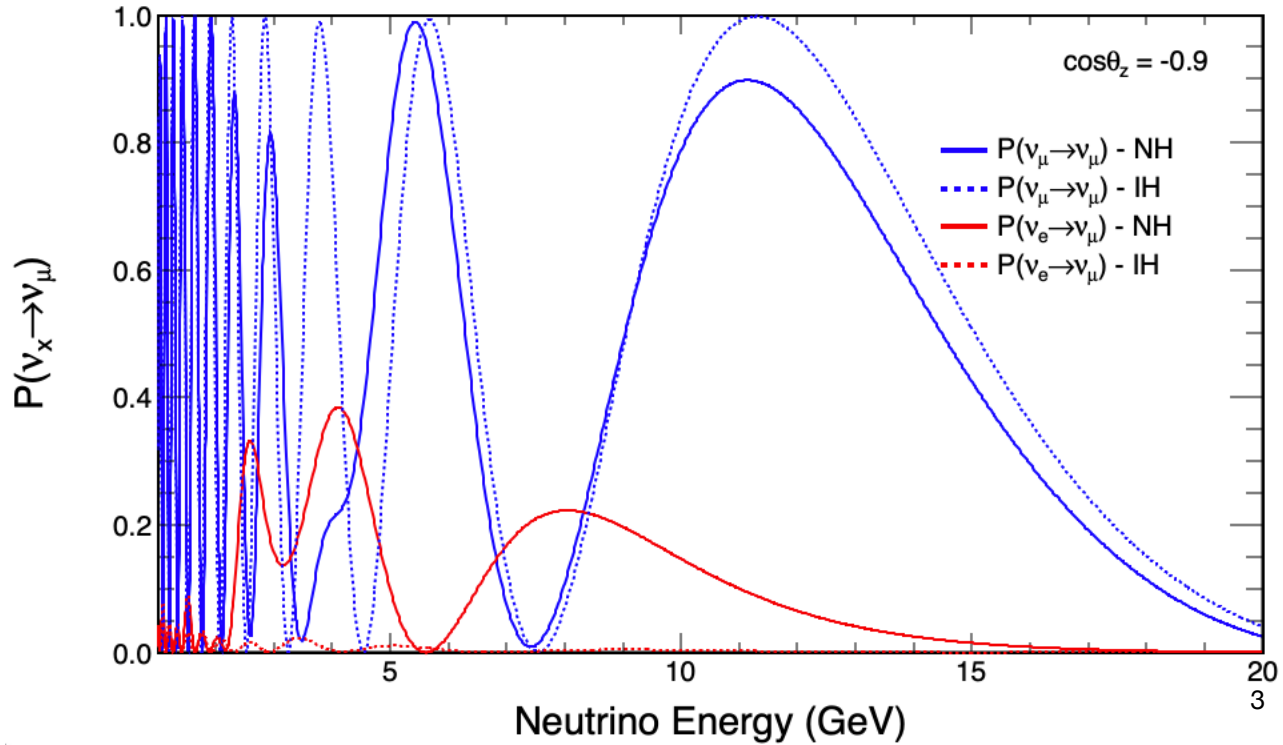
Vacuum mixing angle

Matter mixing angle

neutrino/antineutrino



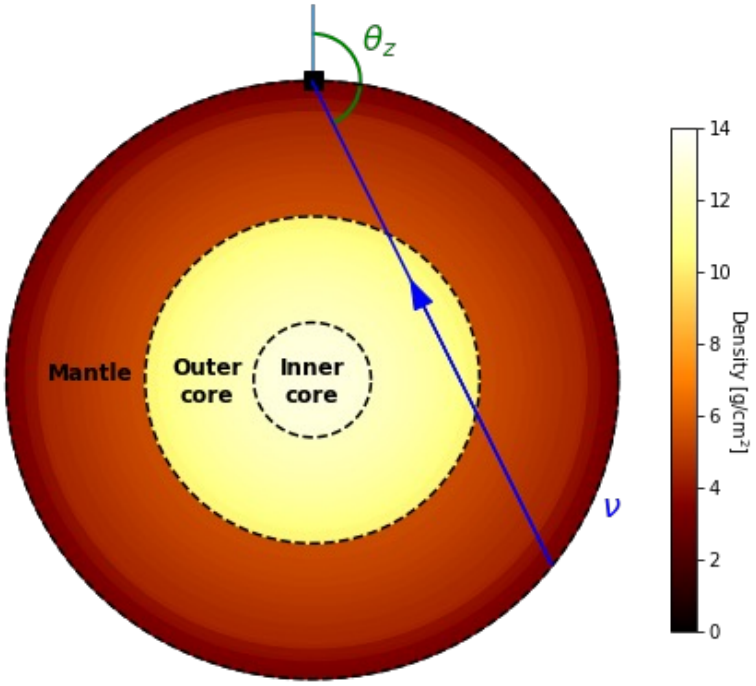
Adrián-Martínez *et al.* 'Letter of Intent for KM3NeT 2.0'

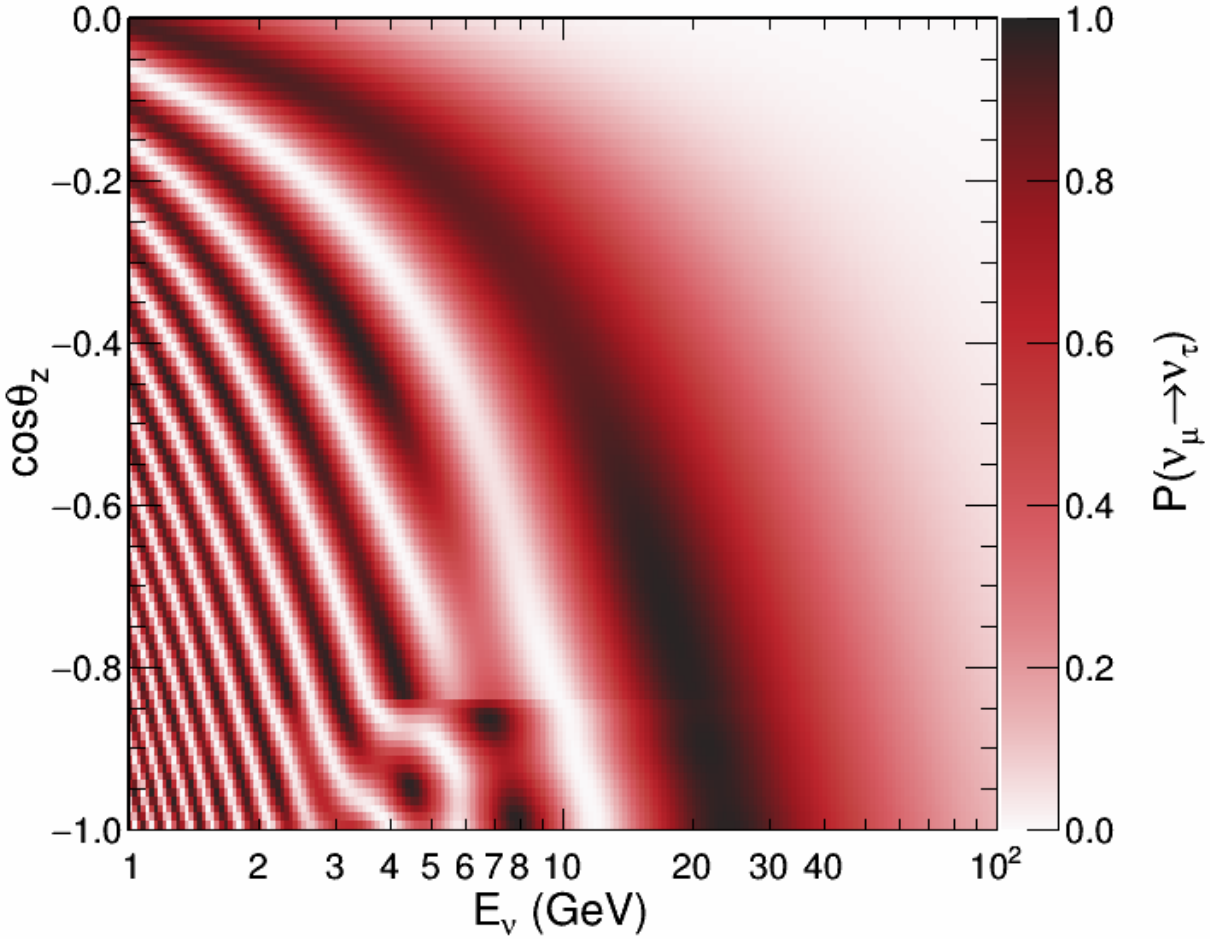


Measure neutrino oscillations

Requirements:

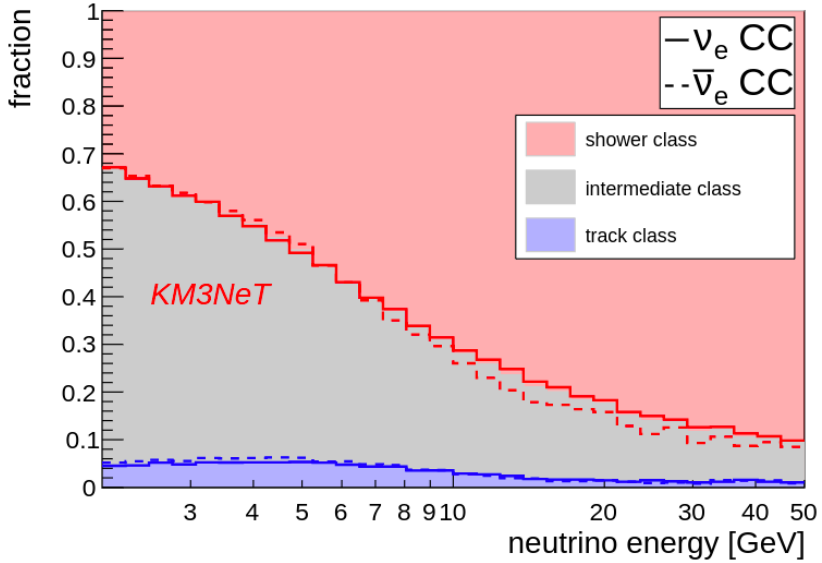
- Energy and angular resolution
- Flavour identification

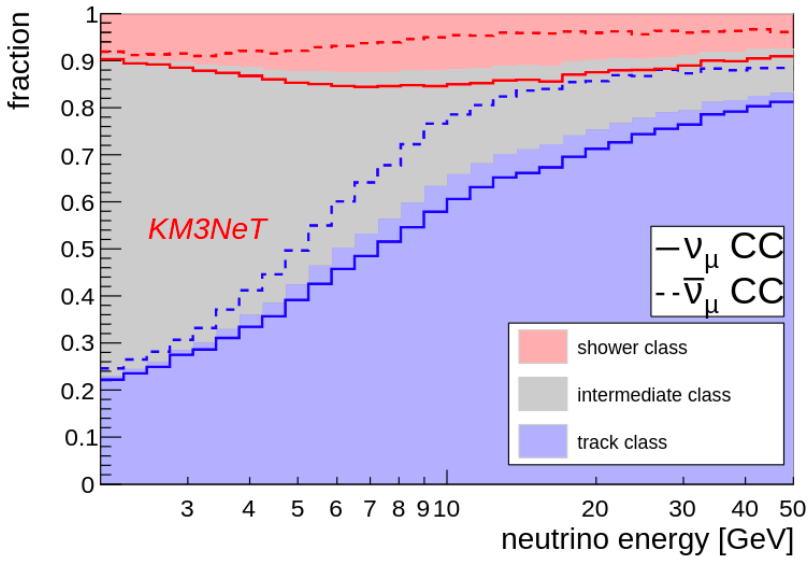


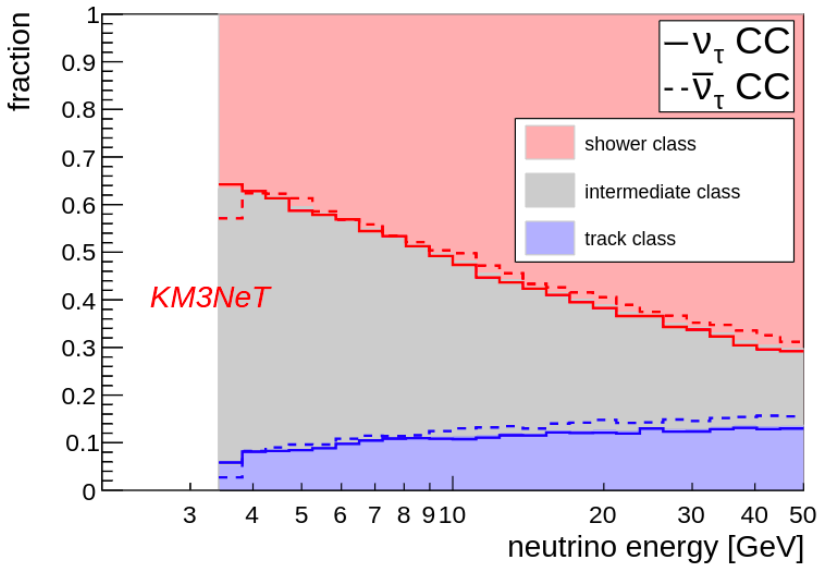


Neutrino Mass Ordering: Particle identification

- Light distribution in detector depends on neutrino flavour and interaction channel (Charged/Neutral Current)
- Random decision forest (RDF) for classification into:
  - track-like (ν_μ-CC) and shower-like (ν_e-CC + ν-NC)
  - Atmospheric μ and ν
  - Noise (bioluminescence, ^{40}K-decay) and ν
- Training features: Fit likelihoods, PDFs of hit expectations etc.







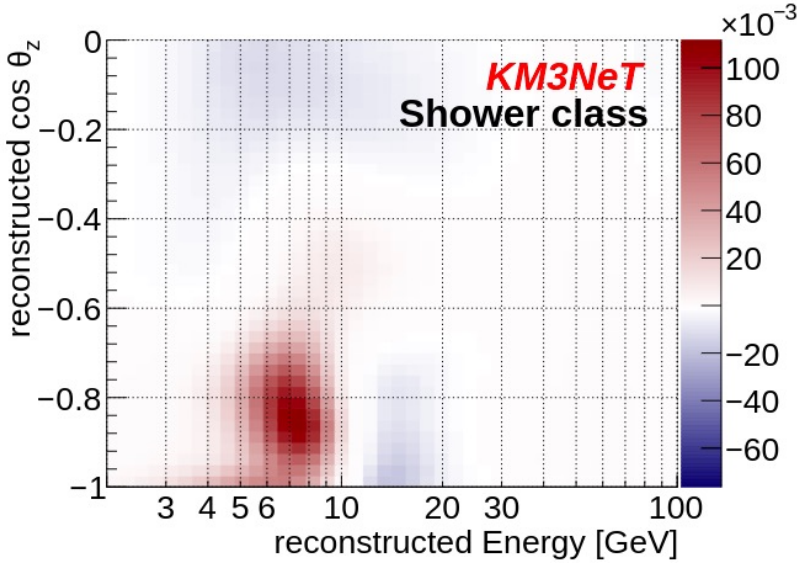
arXiv:2103.09885 [hep-ex]

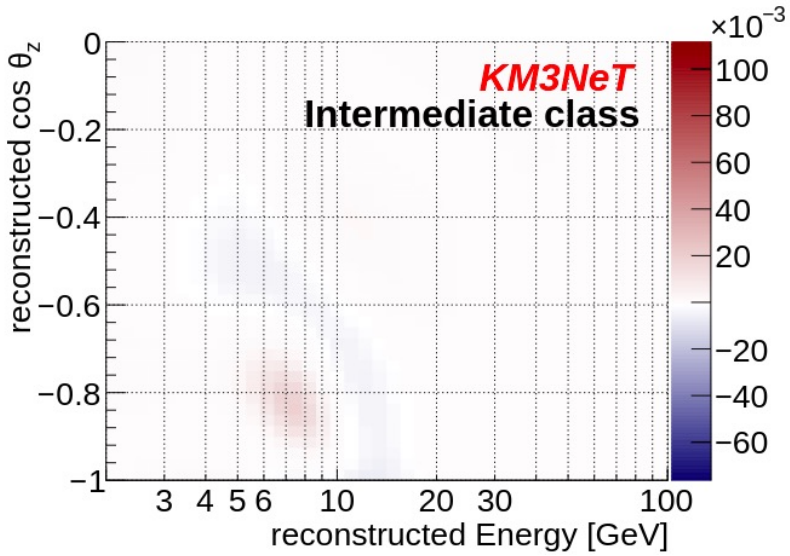
Neutrino Mass Ordering: Sensitivity

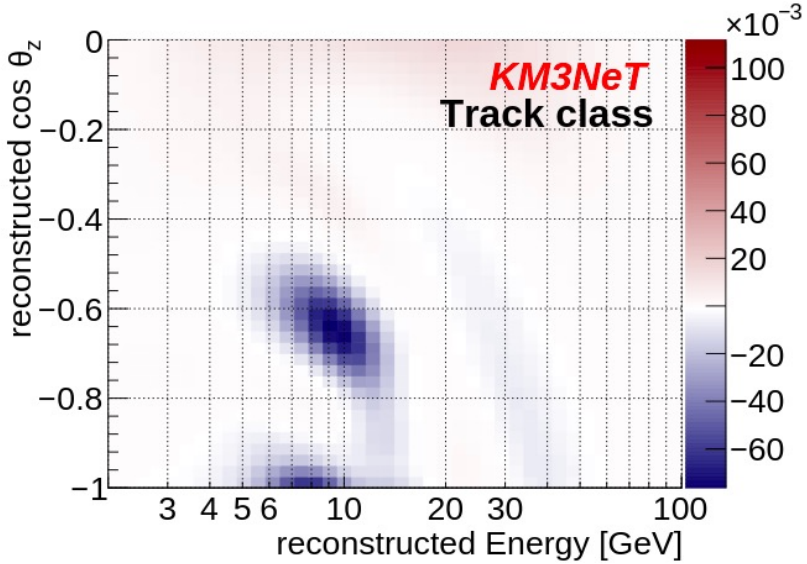
NMO sensitivity analysis:

- Select events (upgoing, contained in instrumented volume..)
- Define shower/intermediate/track class
- Hypothesis test: Normal Ordering (NO) vs. Inverted Ordering (IO):

$$\Delta\chi^2 = \frac{n_{NO} - n_{IO} \times |n_{NO} - n_{IO}|}{n_{NO}}$$



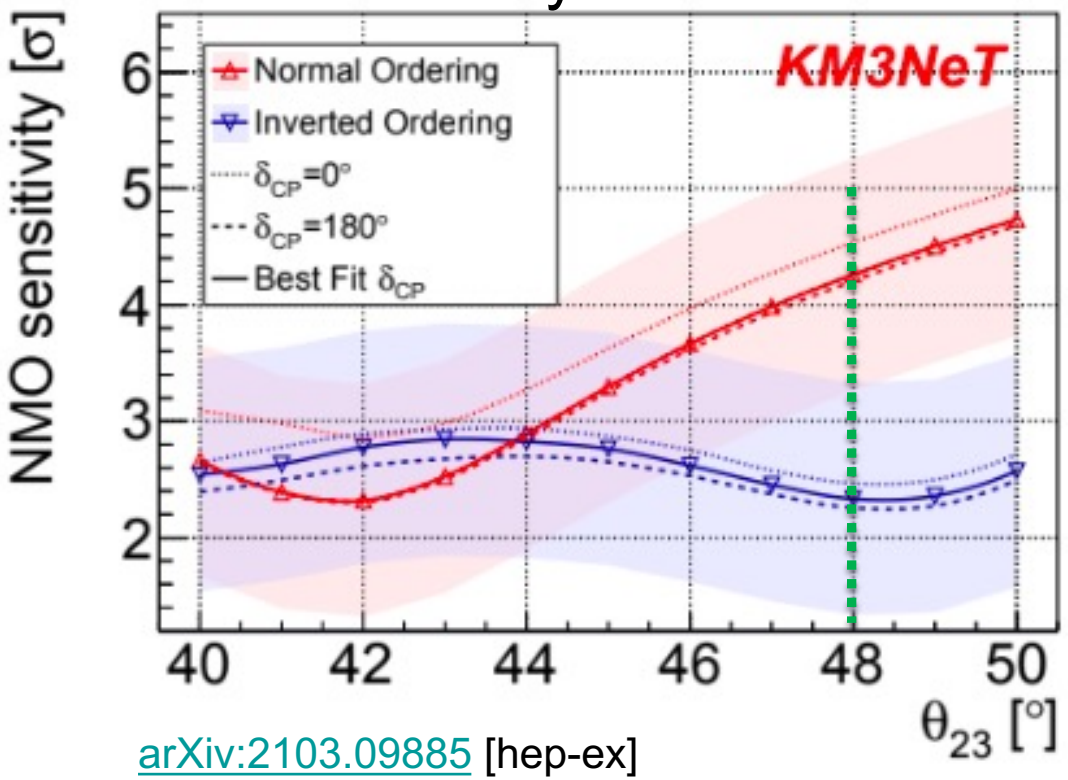




arXiv:2103.09885 [hep-ex]

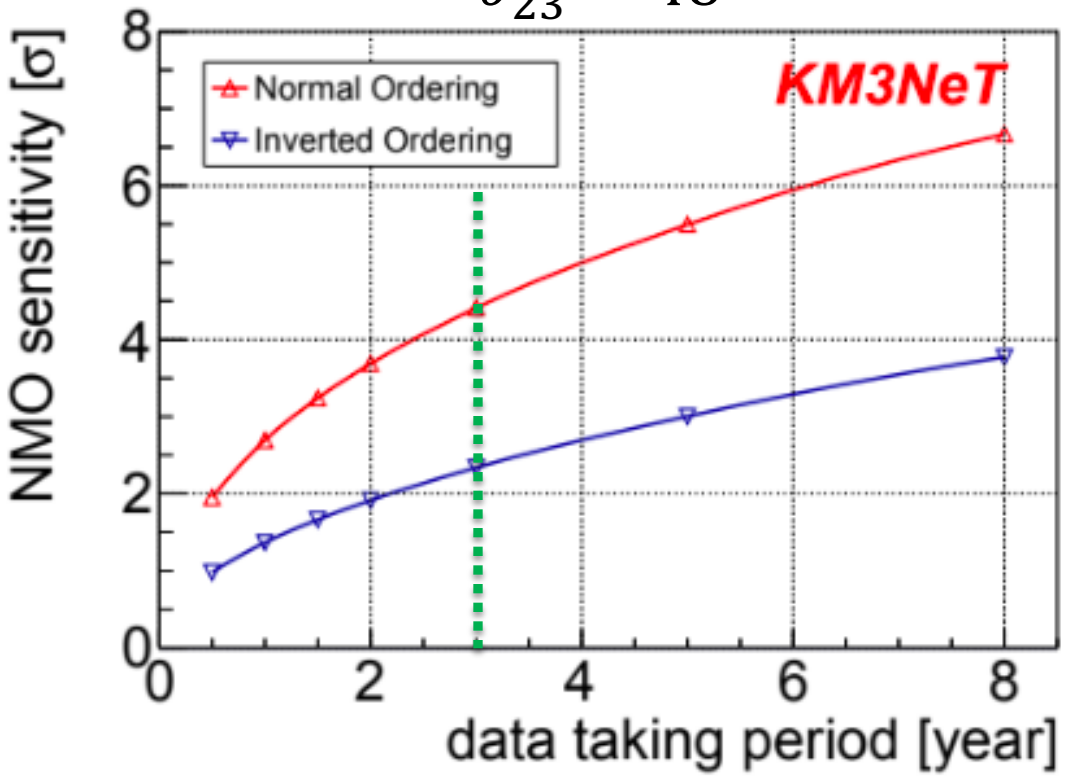
NMO: Sensitivity

3 years



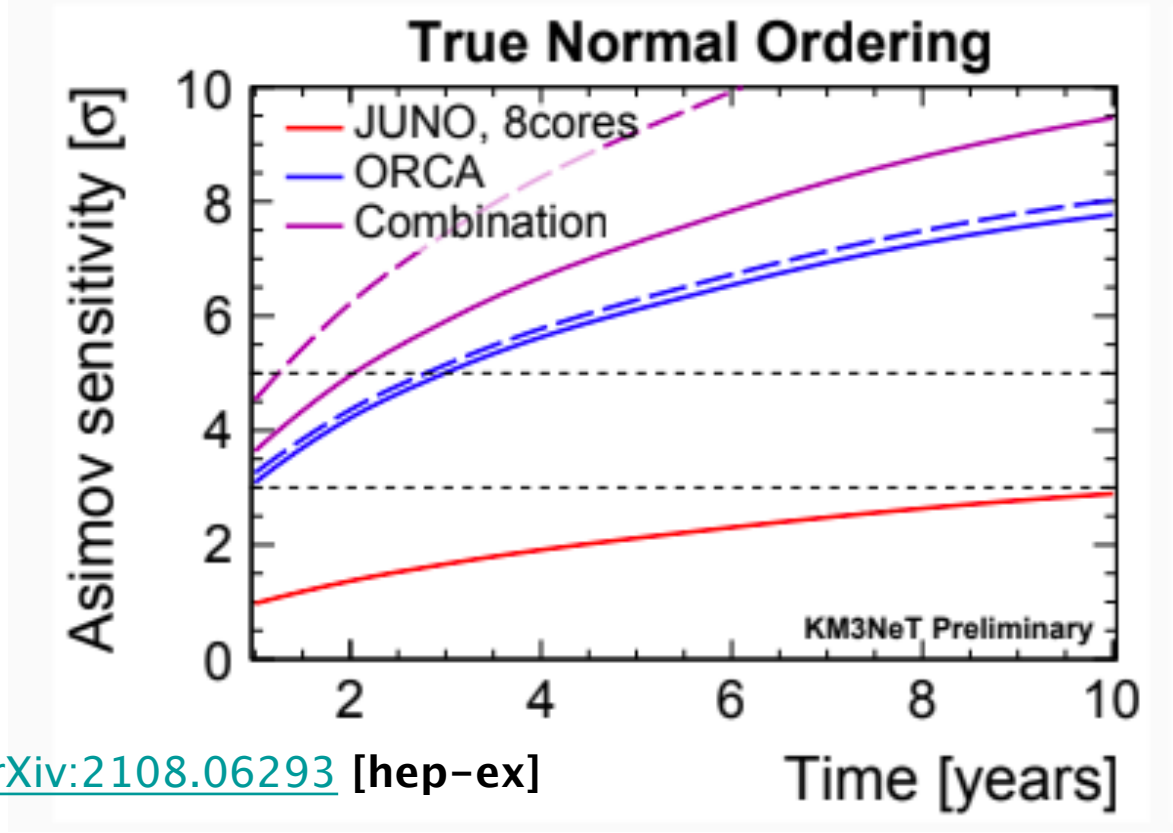
arXiv:2103.09885 [hep-ex]

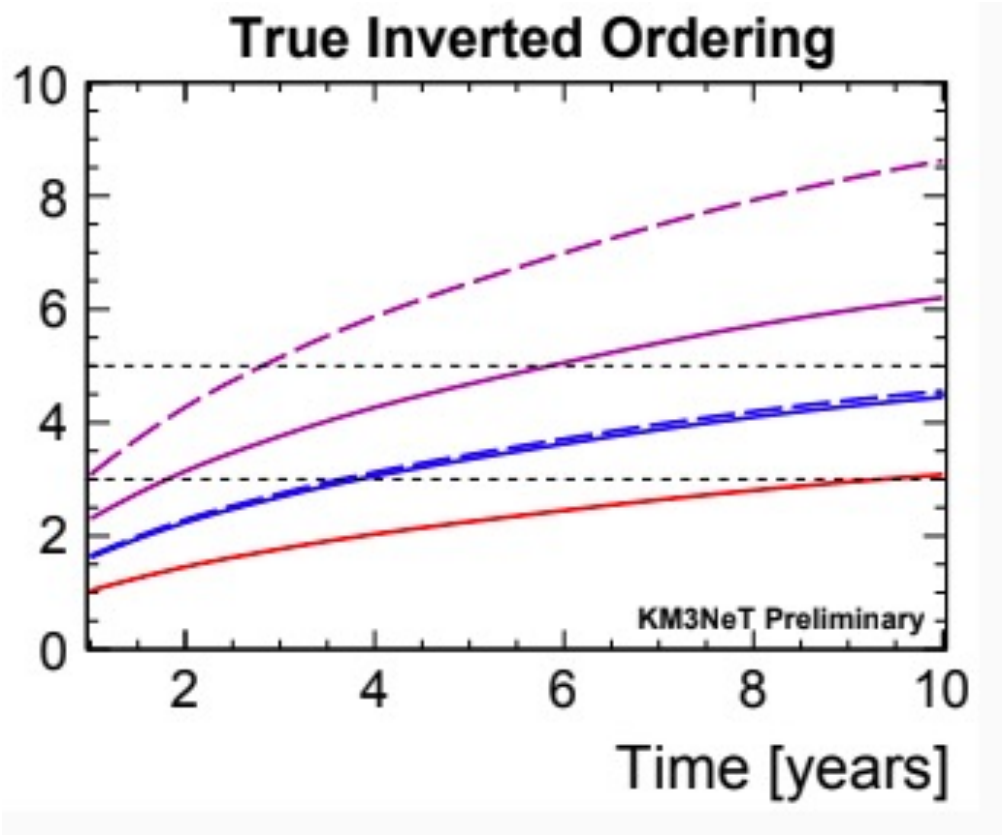
$\theta_{23} = 48°$



NMO sensitivity after 3 years: 4.4(2.3)σ, NO(IO)

NMO: combination with JUNO

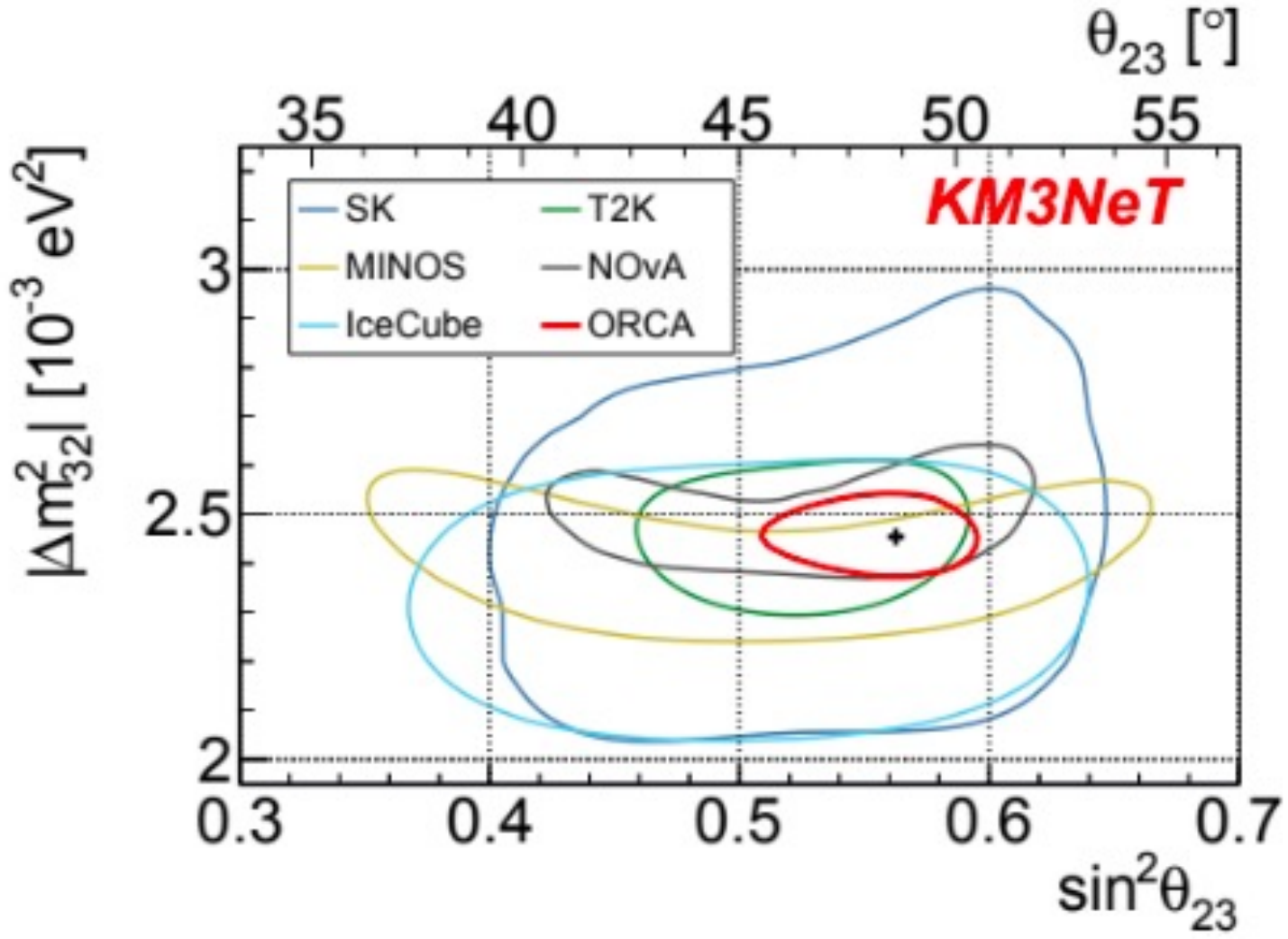




arXiv:2108.06293 [hep-ex]

Sensitivity boost due to Δm_{31} disagreement for wrong NMO hypothesis

Measurements of the oscillation parameters



arXiv:2103.09885 [hep-ex]

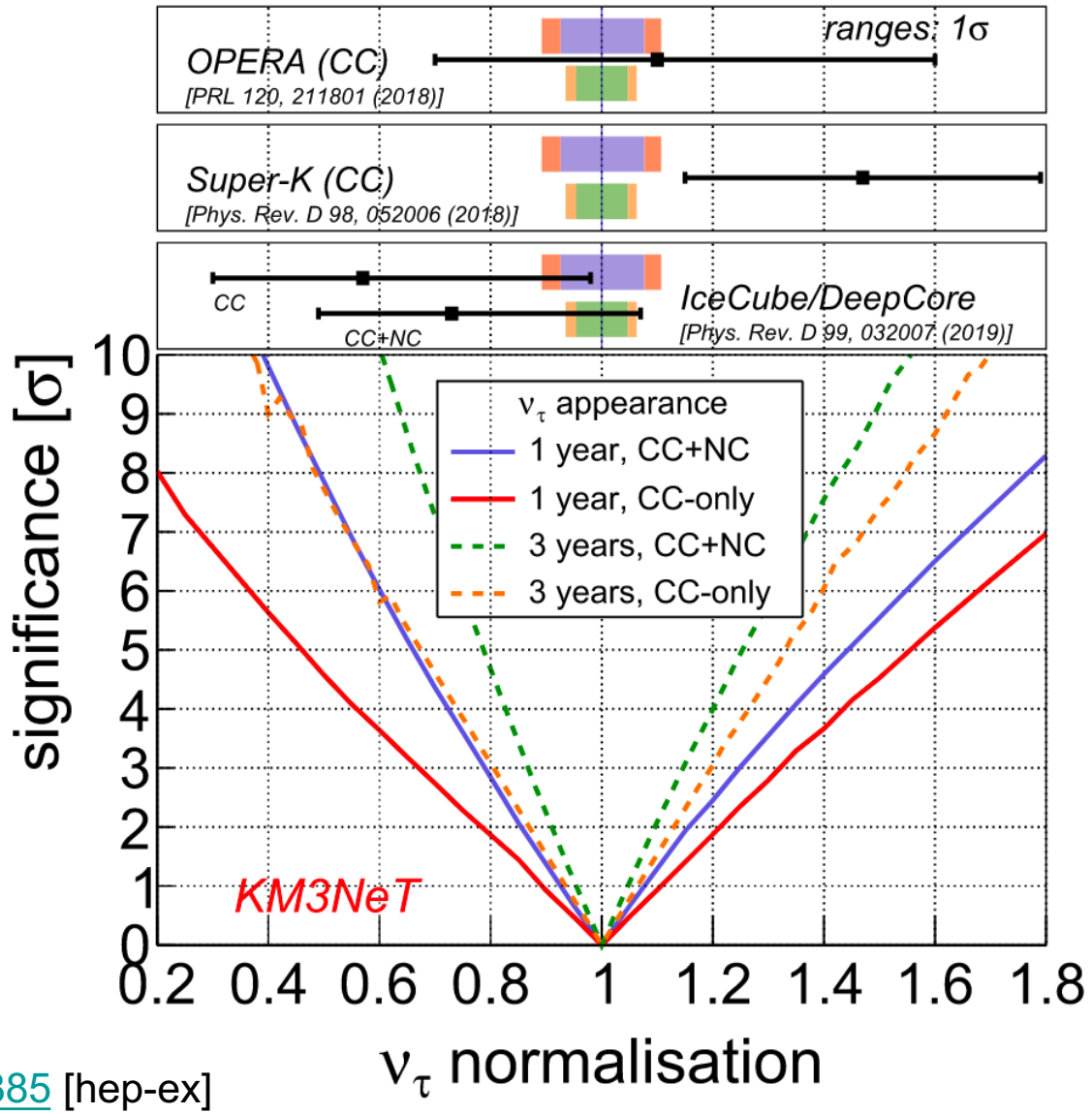
90% C.L. for Δm^2_{32} and $\sin^2\theta_{23}$ with **3 years** ORCA

ν_τ-appearance

Fit normalisation factor of expected events from $\nu_x \rightarrow \nu_\tau$ oscillations

⇒ Measure τ-sector of PMNS matrix

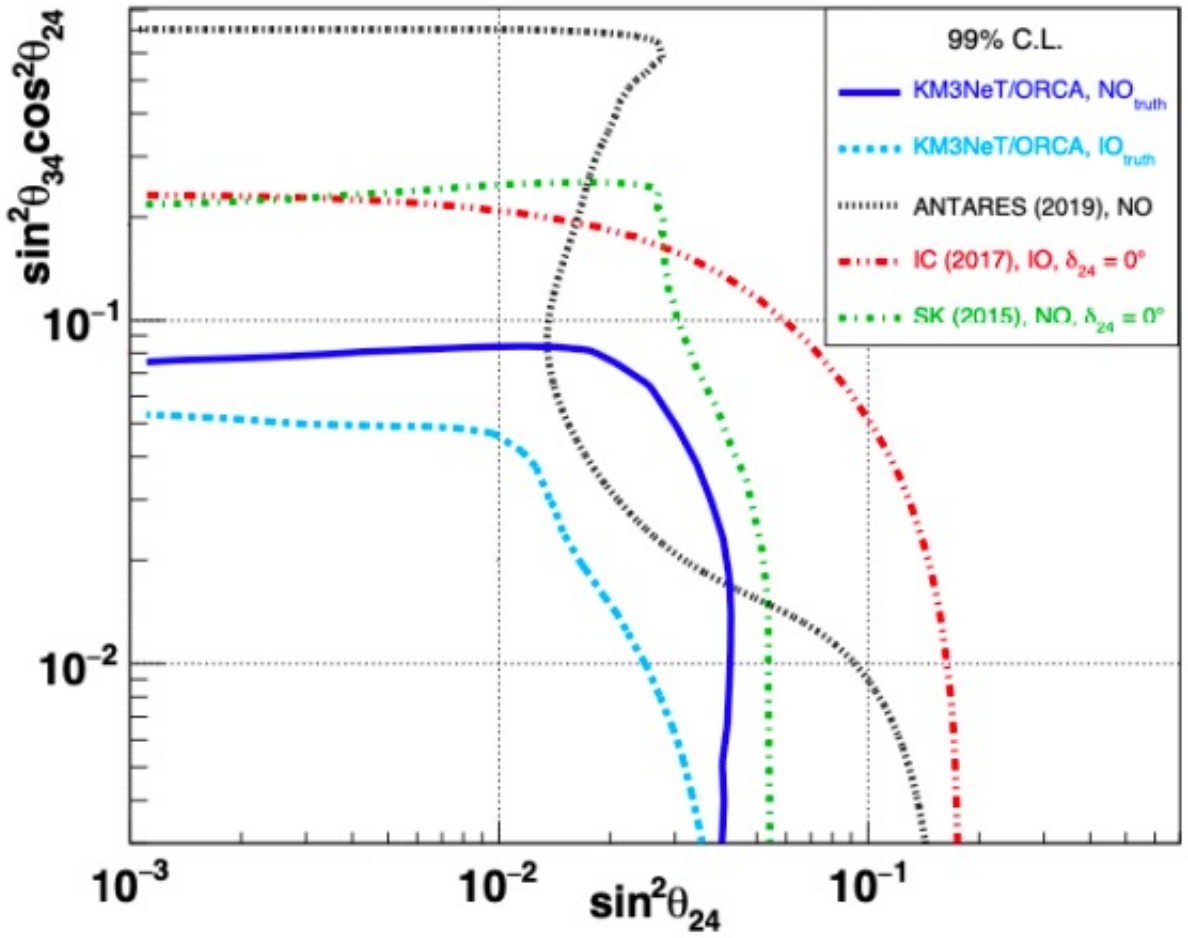
⇒ Test PMNS unitarity



arXiv:2103.09885 [hep-ex]

Sterile Neutrinos

- 3+1 model adds:
  - 3 mixing angles θ_{14}, θ_{24}, θ_{34}
  - 2 CP-violating phases δ_{14}, δ_{24}
  - 1 mass term Δm^2_{41}(here $1\mathrm{eV}^2$)
- Strong impact of δ_{24}:
  Free for ANTARES and ORCA
- Results for 3 years of simulated data



https://doi.org/10.1007/JHEP10(2021)180

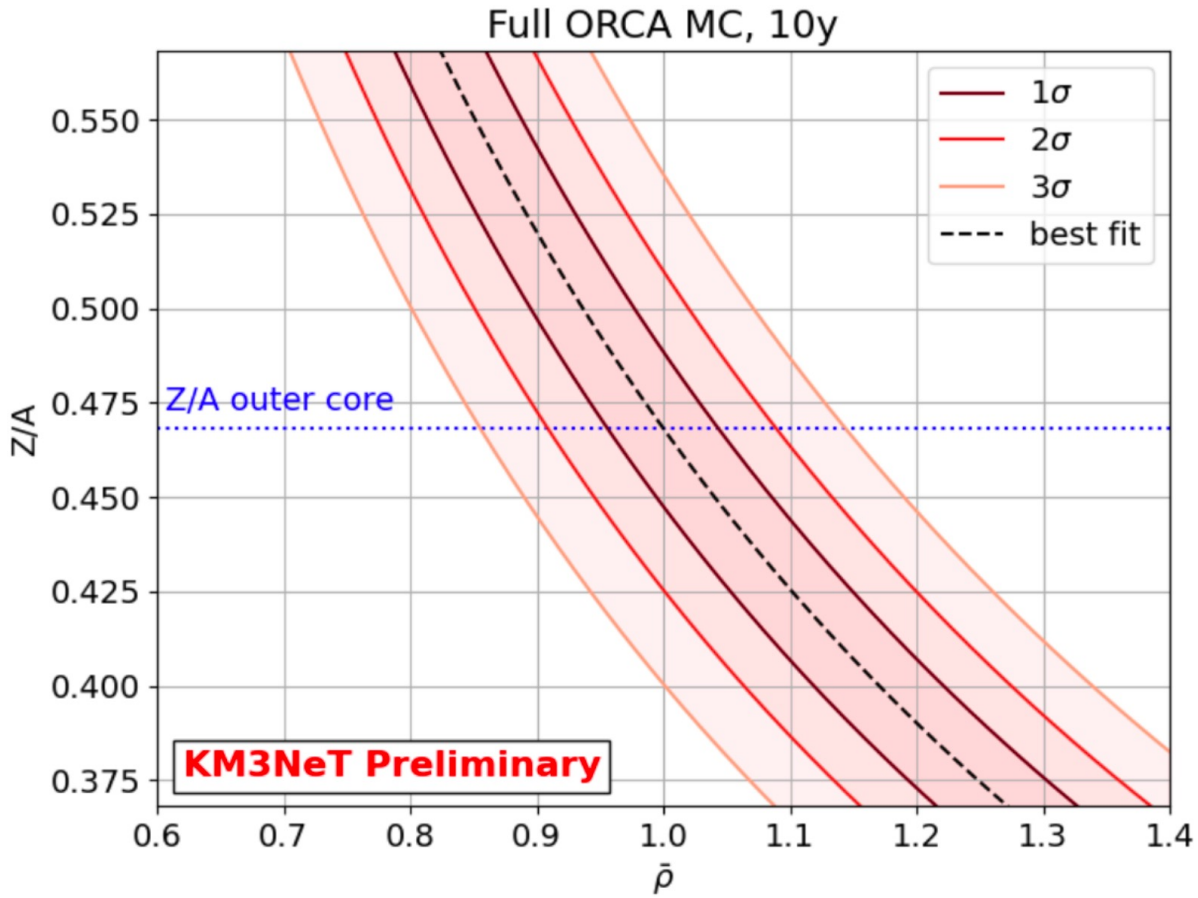
Oscillation tomography of the Earth

Matter resonance dependent on electron density

$$n_e \sim \rho_m \times Z/A$$

⇒Constrain chemical composition in the outer core

⇒Density profiling of the Earth

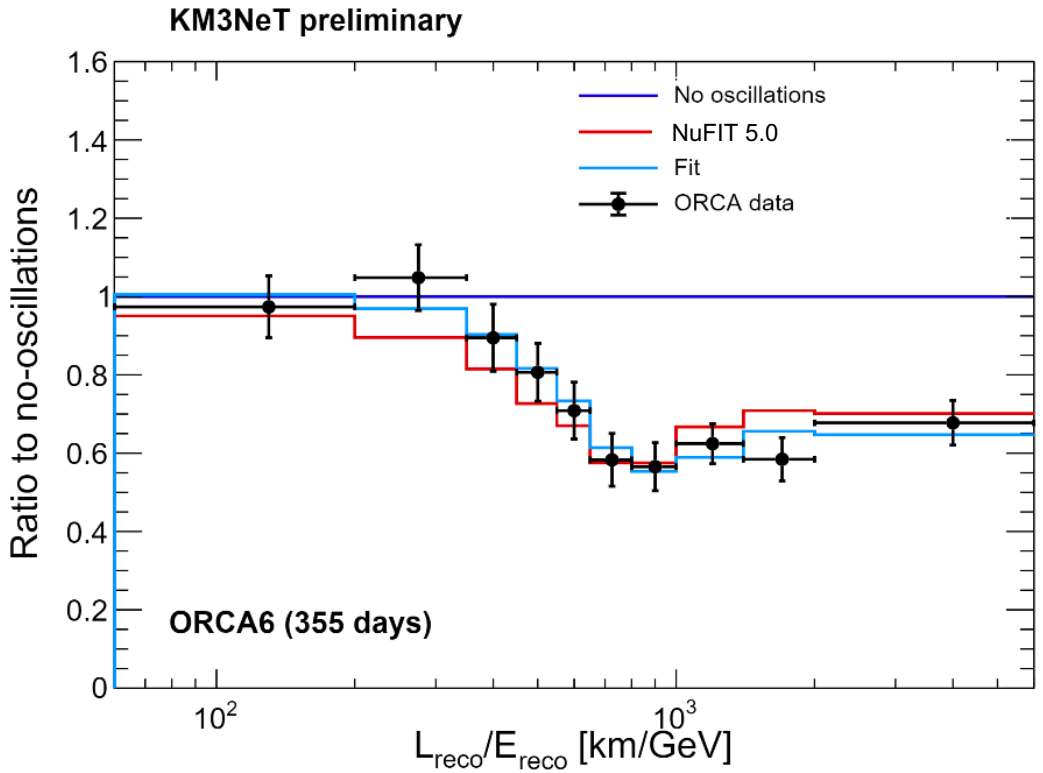


https://doi.org/10.22323/1.395.1172

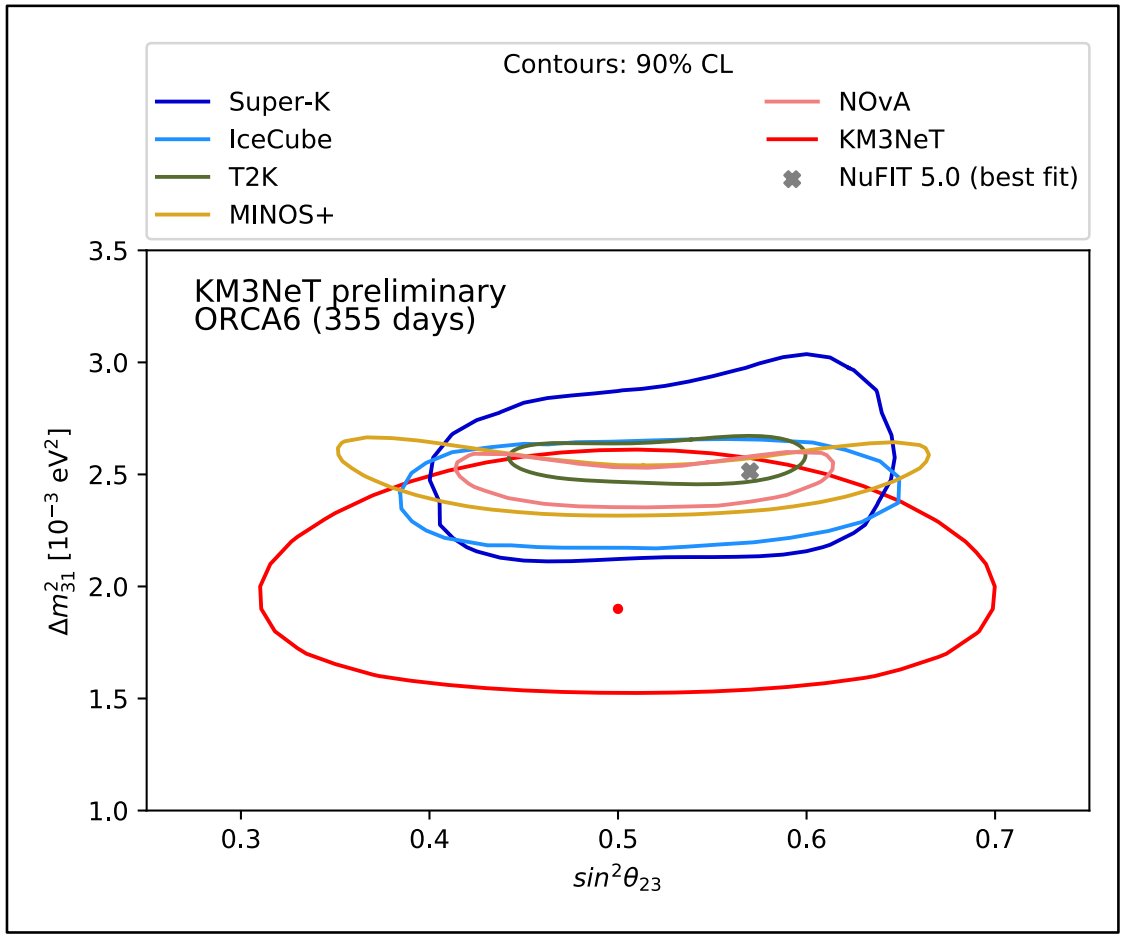
First results: ORCA6

1 year data with 6 ORCA DUs:

- Exclude “no oscillation” hypothesis with 5.9σ

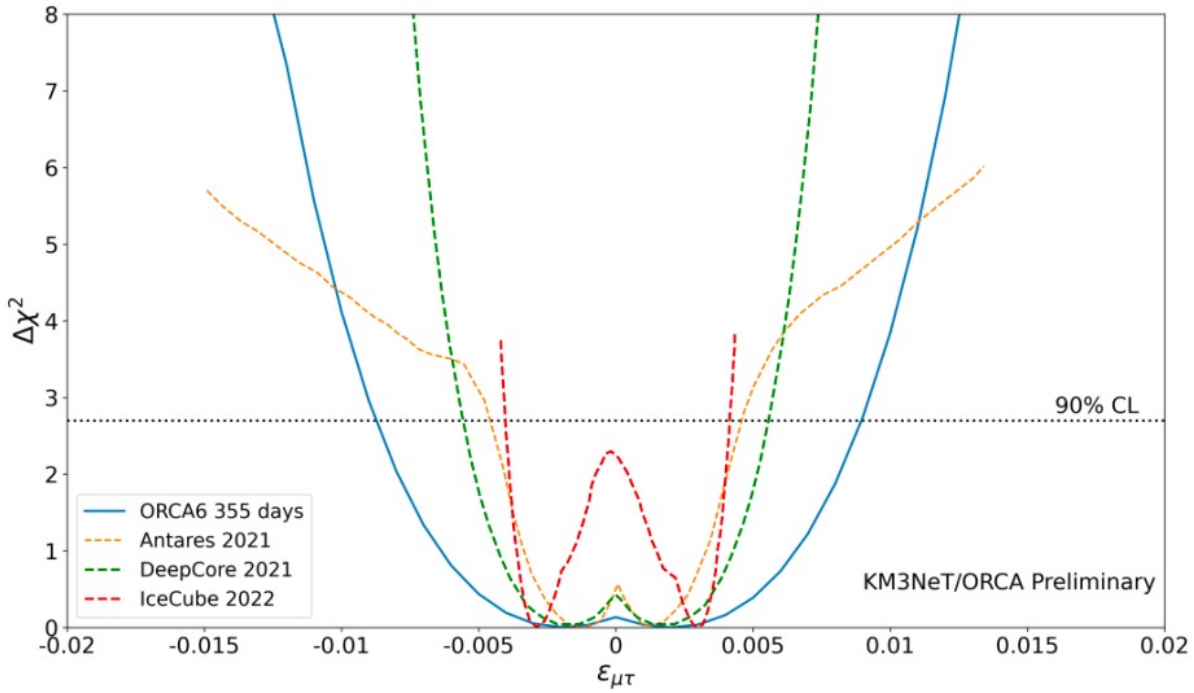


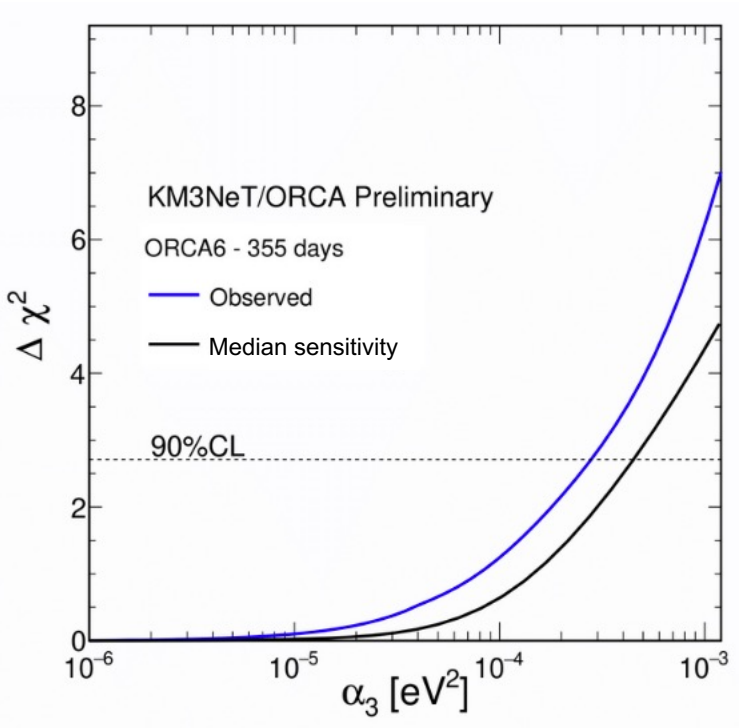
- Measured Δm^2_{31} and θ_{23} in agreement with other experiments



https://doi.org/10.22323/1.395.1123

New physics with ORCA





Constraining non-standard interactions:

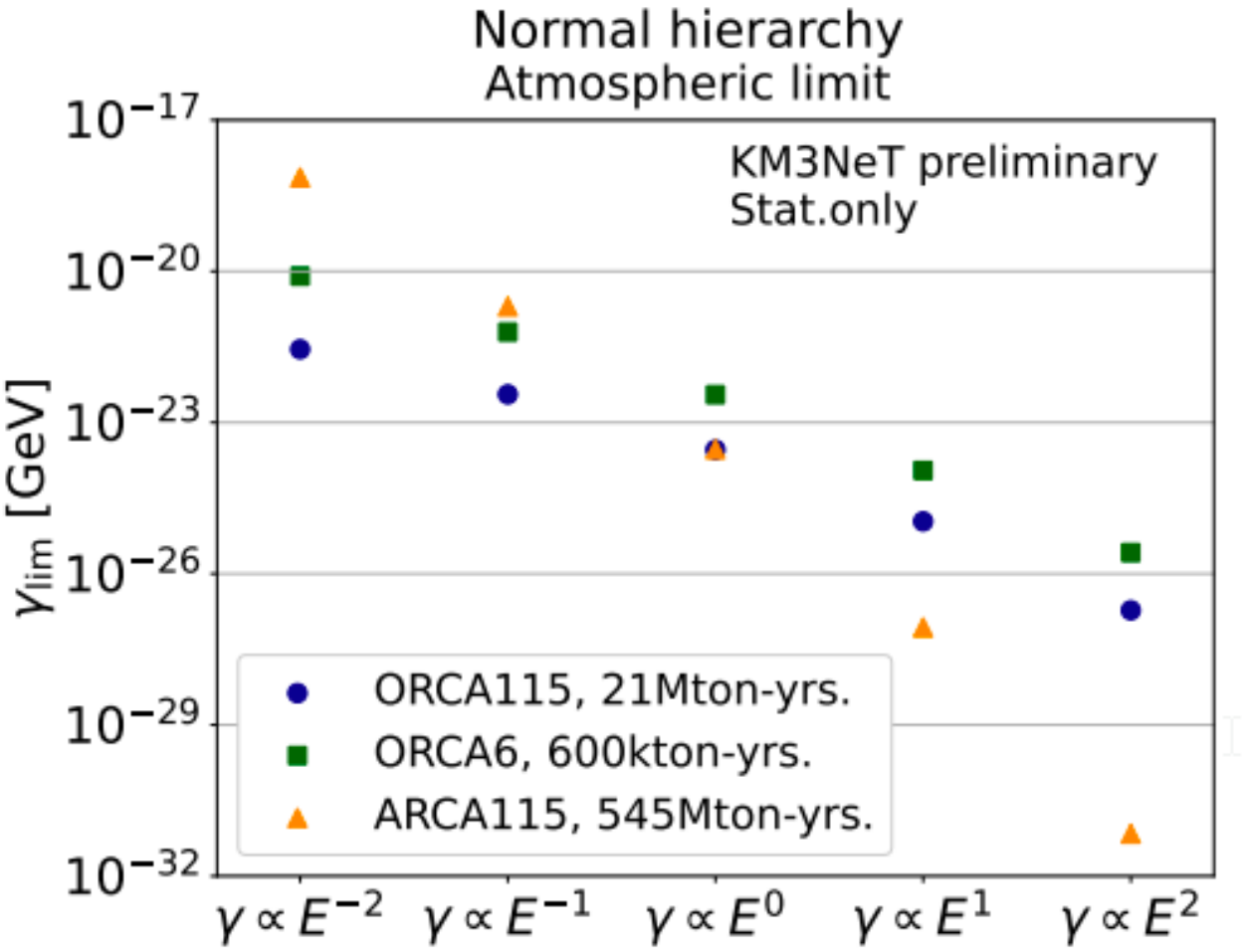
- 1 year ORCA6 already starting to become competitive with similar experiments

Neutrino decay/lifetime:

- ORCA6: proof of concept
- Full ORCA: leading sensitivity of single detector

10.5281/zenodo.6785232

Decoherence

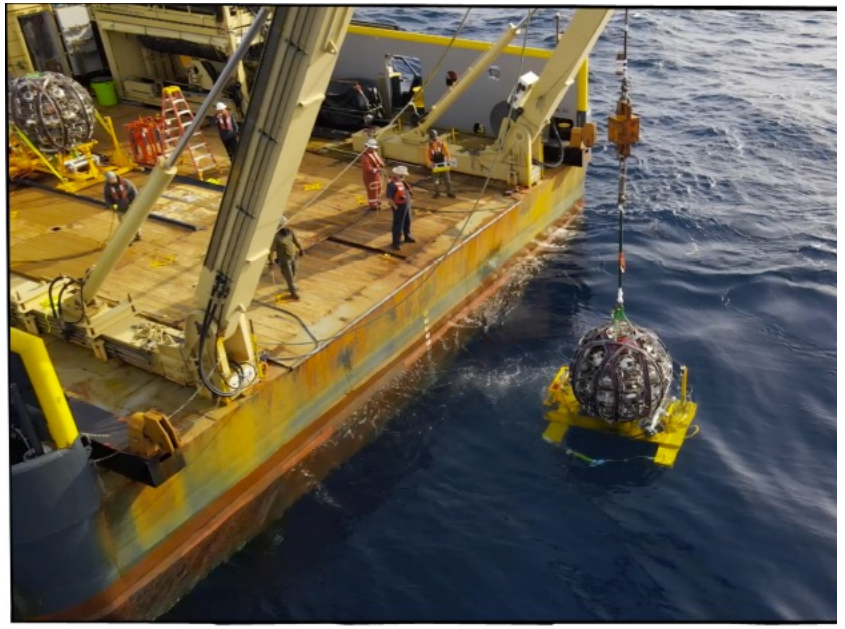


10.5281/zenodo.6781032.

Neutrino decoherence damps oscillations damping parameter

Summary and outlook

- First results with 6 strings published
  → detector and analysis understood
- Currently 11 strings deployed
  → more to come!

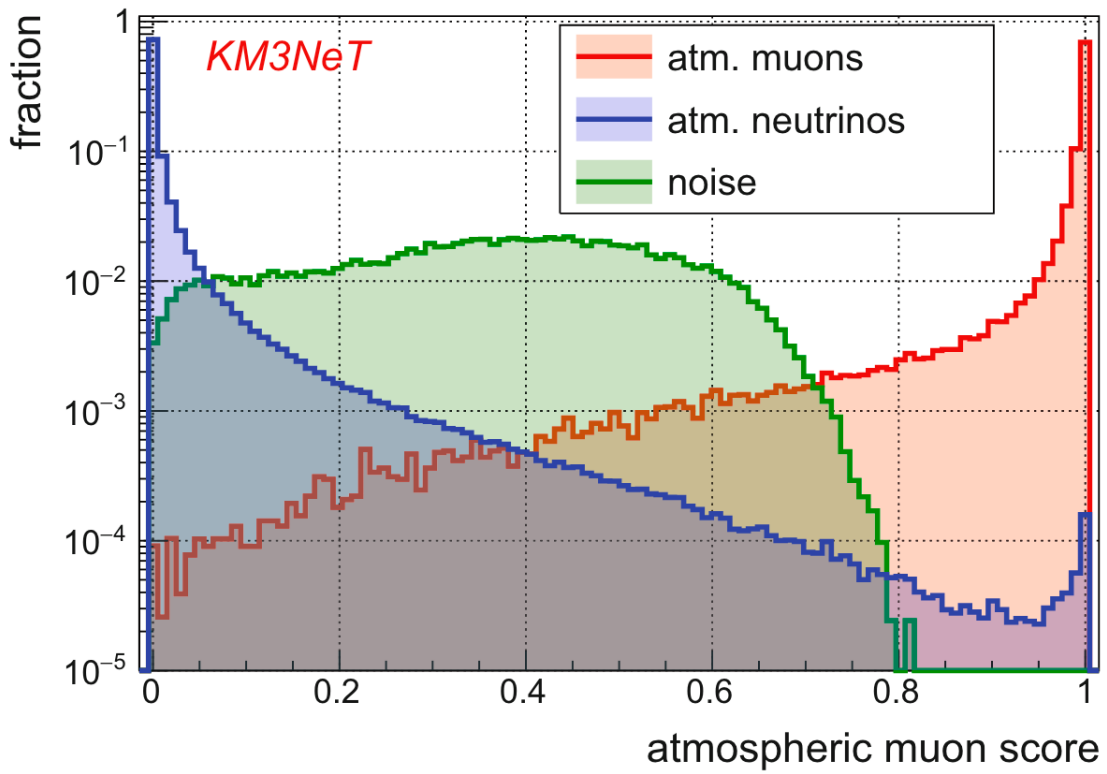


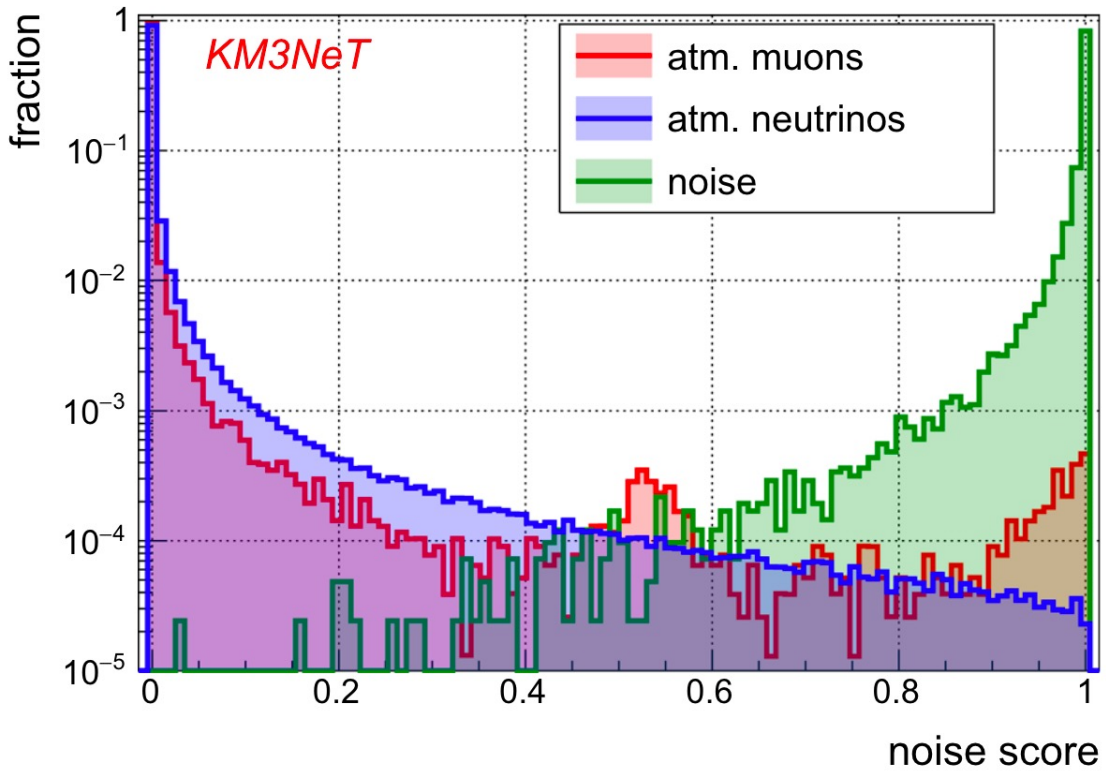
Full detector will be able to provide leading sensitivities to:

- Neutrino Mass ordering
- Oscillation measurements
- Physics beyond the standard model

Backup

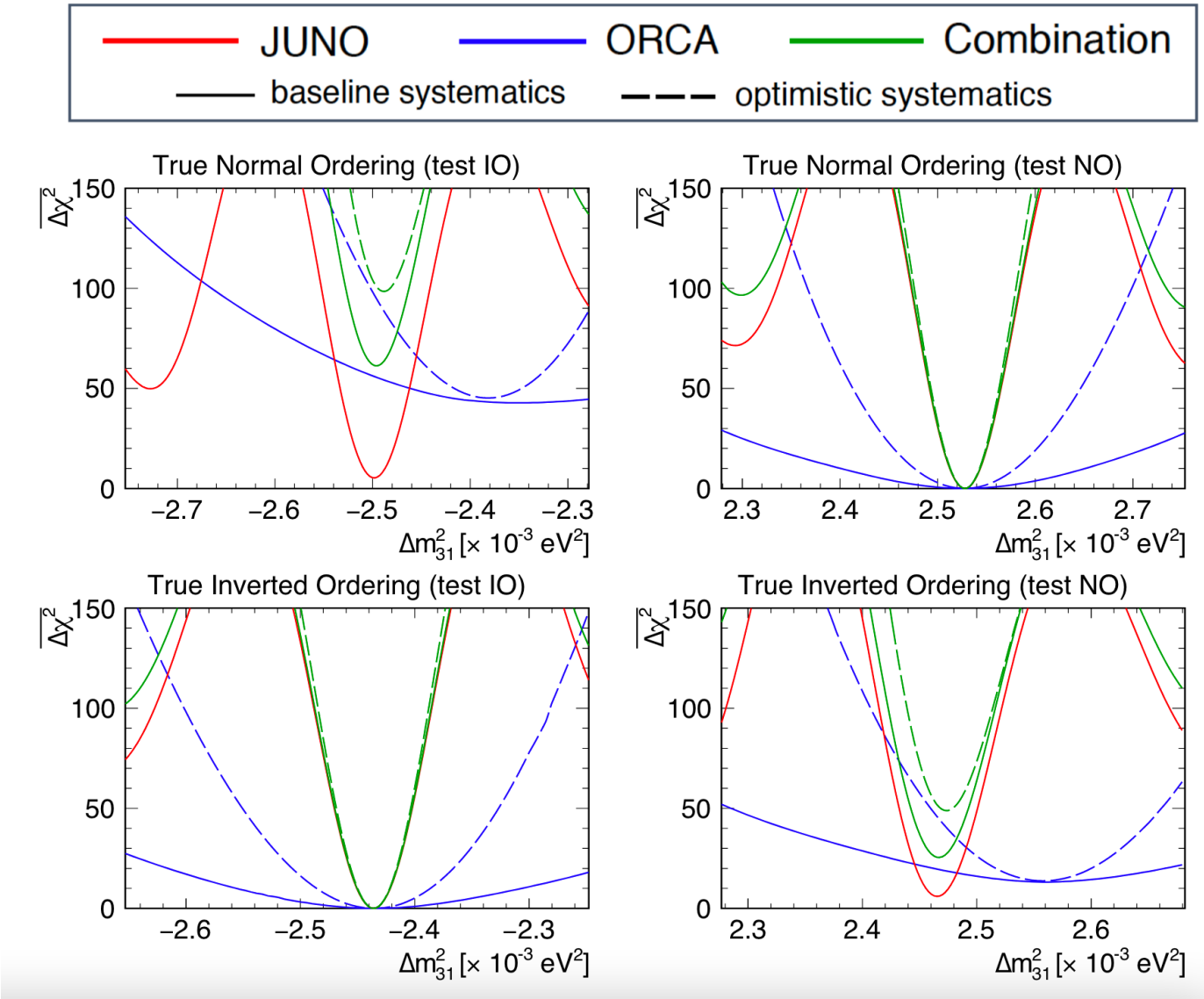
PID: background





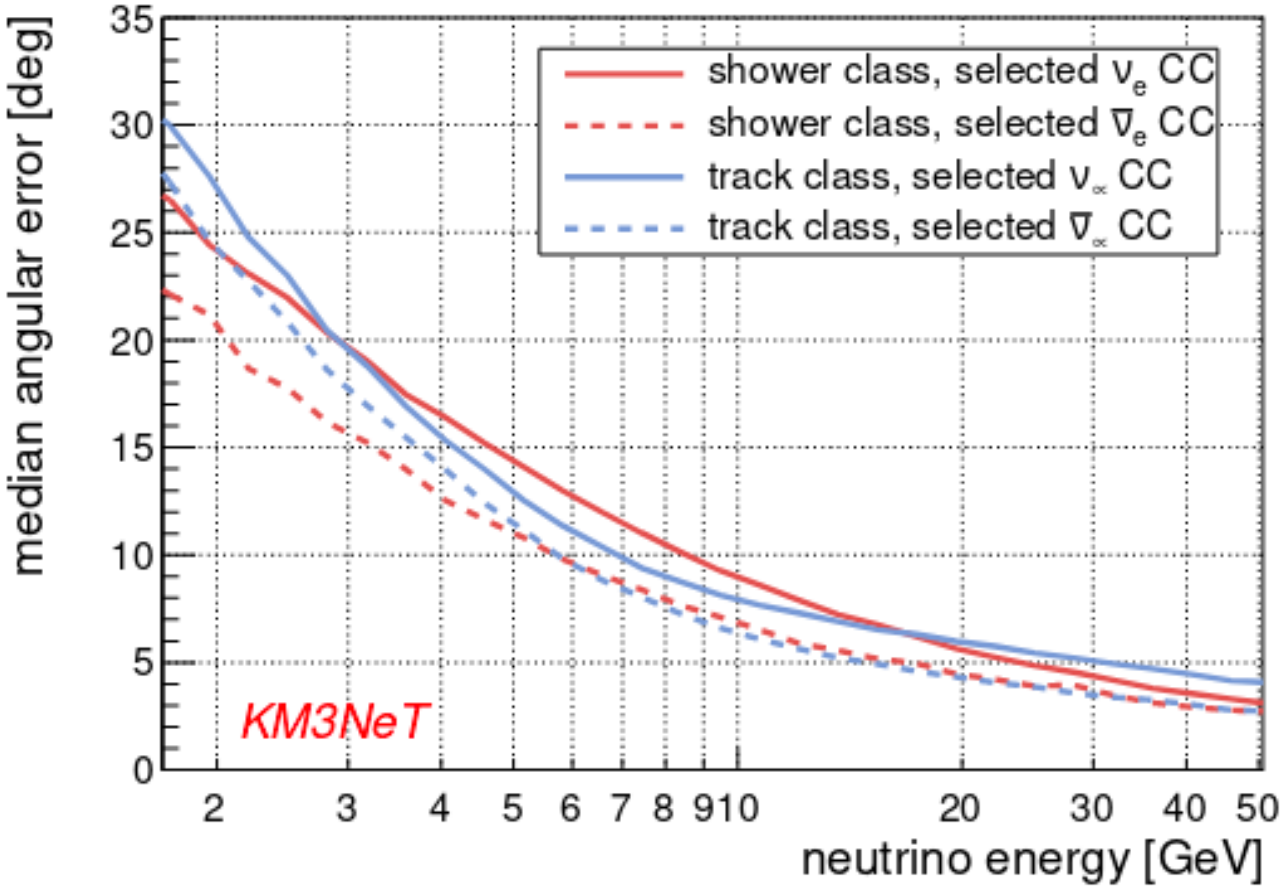
[2]

NMO: JUNO/ORCA combination



[3]

Angular reconstruction



Energy reconstruction