Prospects for Measuring the Neutrino Mass Hierarchy with KM3NeT/ORCA

Jannik Hofestädt (ECAP) for the KM3NeT Collaboration

European Cosmic Ray Symposium, Torino

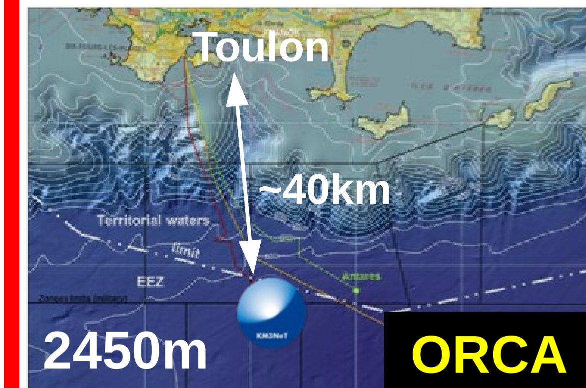
07.09.2016

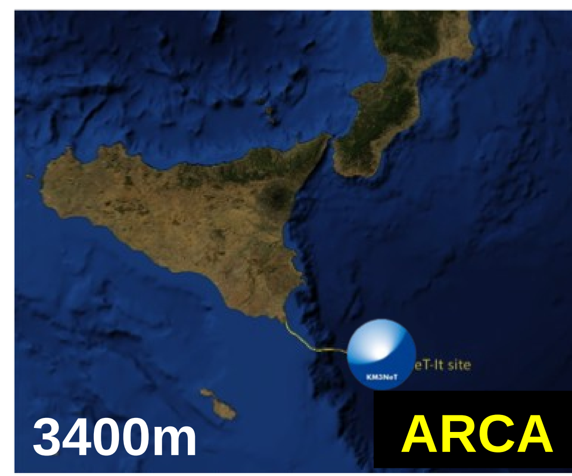
KM3NeT Collaboration

Multi-site deep-sea neutrino research infrastructure

Single collaboration – single technology

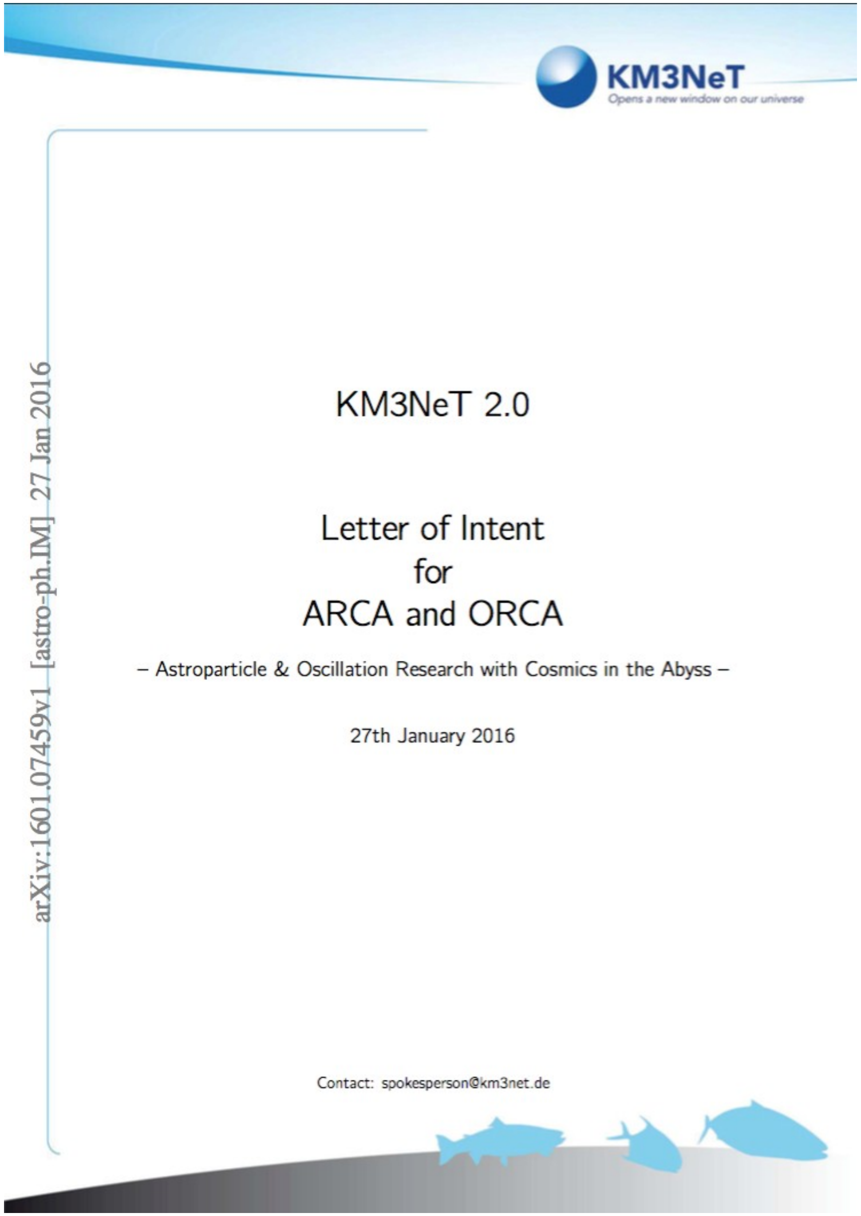
this talk





→ last talk

KM3NeT: ARCA & ORCA


KM3NeT
Opens a new window on our universe

arXiv:1601.07459v1 [astro-ph.IM] 27 Jan 2016

KM3NeT 2.0

Letter of Intent
for
ARCA and ORCA

– Astroparticle & Oscillation Research with Cosmics in the Abyss –

27th January 2016

Contact: spokesperson@km3net.de

Astroparticle **R**esearch with **C**osmics in the **A**byss (**ARCA**)

→ sparse detector optimised for TeV-PeV cosmic neutrinos

→ discover high-energy neutrino sources

Oscillation **R**esearch with **C**osmics in the **A**byss (**ORCA**)

→ dense detector optimised for few-GeV atmospheric neutrinos

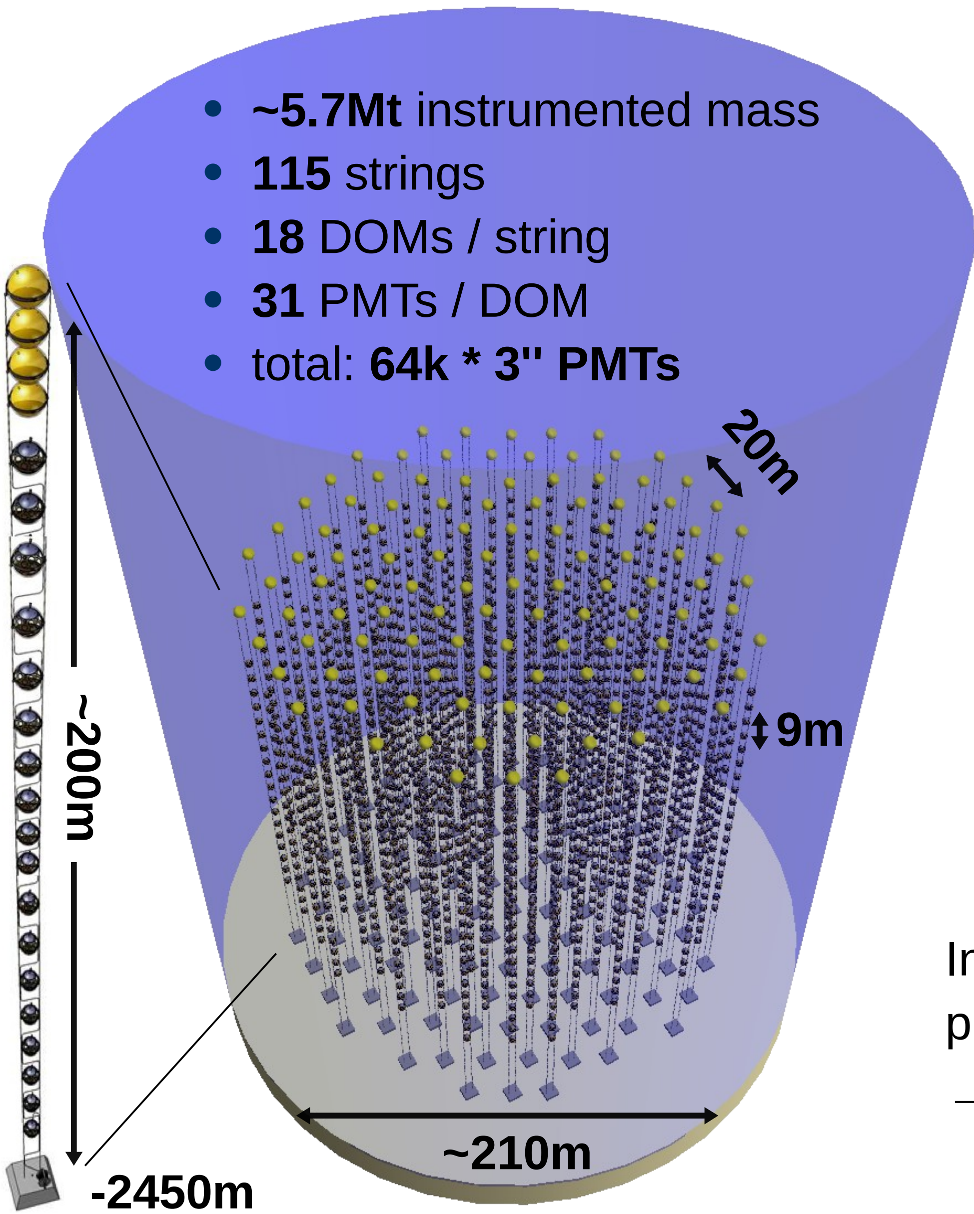
→ determine neutrino mass hierarchy

Letter of Intent

☛ J. Phys. G43 (2016) no.8, 084001

KM3NeT/ORCA Detector

- **~5.7Mt** instrumented mass
- **115** strings
- **18** DOMs / string
- **31** PMTs / DOM
- total: **64k * 3'' PMTs**



Digital Optical Module (DOM)

- 31 x 3'' PMTs (19 ↓, 12 ↑)
- Uniform angular coverage
- Directional information
- Single photon counting

Instrumentation density driven by main physics goal: neutrino mass hierarchy

→ ~few-GeV neutrinos

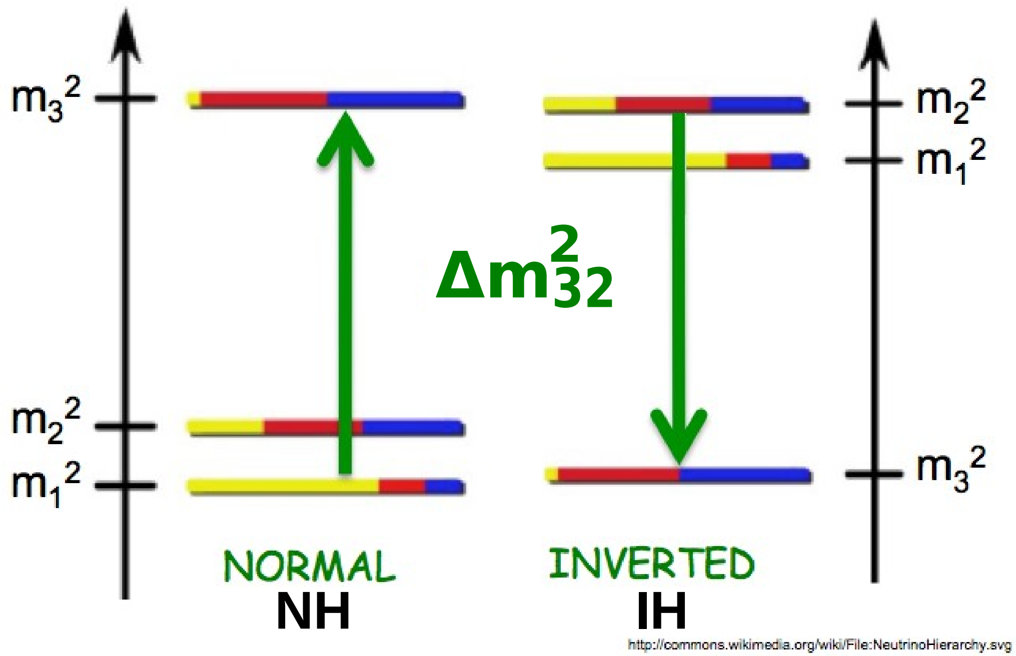
(~80x denser than ARCA)

ORCA's Goal: Neutrino Mass Hierarchy

- Neutrinos can change flavour ('neutrino oscillation')

- 'Knowns':
  - mixing angles θ_{12}, θ_{13}, θ_{23}
  - $|\Delta m^2_{32}|$, Δm^2_{21}
- 'Unknowns':
  - CP phase δ
  - sign (Δm^2_{32}), i.e.

    mass hierarchy (MH)
  - absolute neutrino masses



- MH important for:
  - neutrino mass models
  - design and interpret other experiments (δ_{CP}, $0\nu2\beta$)

Resonance and Atmospheric Neutrinos

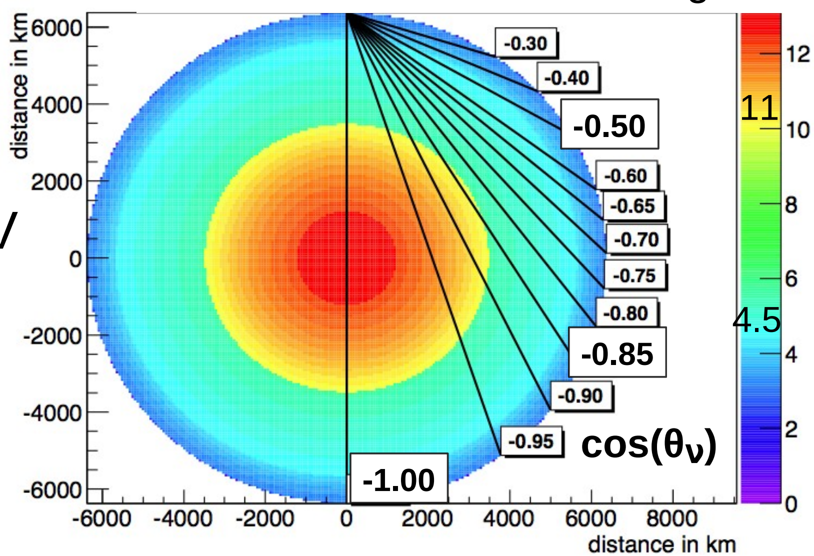
- In vacuum: oscillation unaffected by MH
- In matter: resonance* in oscillation probabilities for ν in NH and for $\bar{\nu}$ in IH

$$E_{\nu,res} \approx \frac{30}{\rho[\mathrm{g/cm^3}]}\ \mathrm{GeV}$$

- Earth density profile → $E_{\nu,res}$ = 3–7 GeV
- Atmospheric neutrinos ideally suited
  - → known composition ($\nu_e, \bar{\nu}_e, \nu_\mu, \bar{\nu}_\mu$)
  - → wide range of energies & baselines

*MSW effect
S. P. **M**ikheyev and A. Yu. **S**mirnov, Sov. J. Nucl. Phys.42, 913 (1985)
L. **W**olfenstein, Phys. Rev. D17, 2369 (1978)

Earth Model



after A.M. Dziewonski, D.L. Anderson, Phys. Earth Planet. Inter., 25 (1981) 297-356

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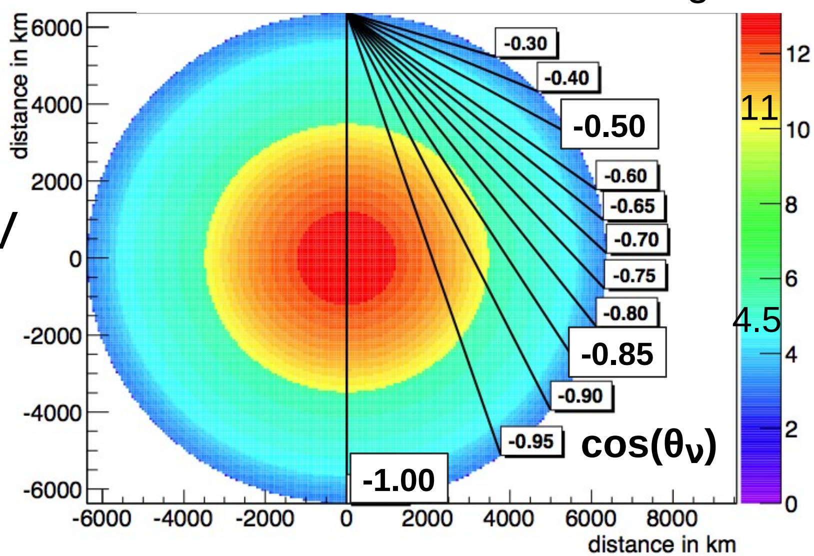

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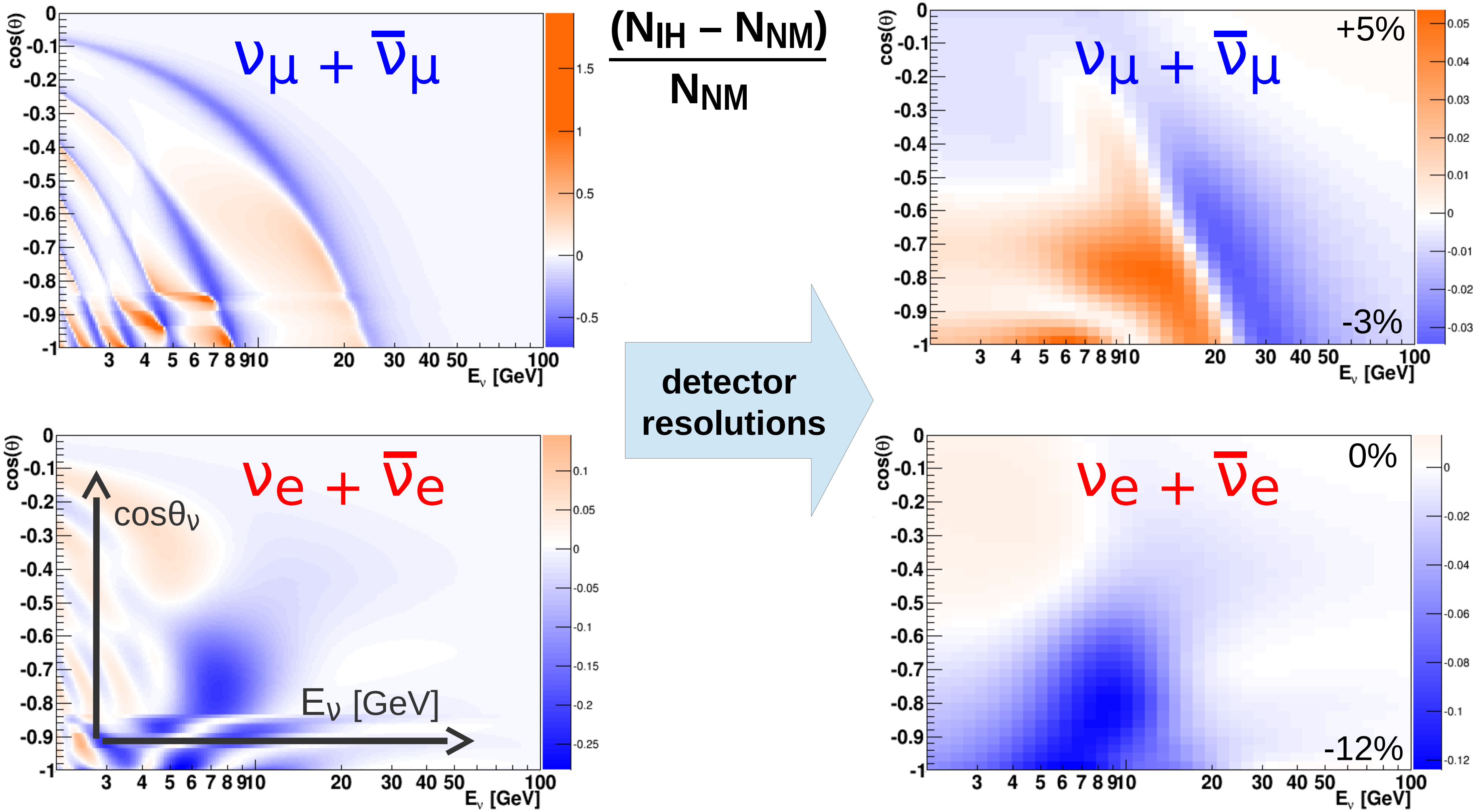
- Opposite matter effect for ν and $\bar{\nu}$: P(ν, NH) ≈ P($\bar{\nu}$, IH)

  BUT differences in cross sections: $\sigma(\nu) \approx 2 \times \sigma(\bar{\nu})$

  and flux: $\Phi_{atm}(\nu) \approx 1.2 \times \Phi_{atm}(\bar{\nu})$

  → few-percent-level net effect even if detector cannot distinguish $\bar{\nu}/\nu$
- **Approach: measure E_ν and θ_ν of upgoing atmospheric GeV-scale neutrinos, identify and count ν_μ and ν_e channel events**

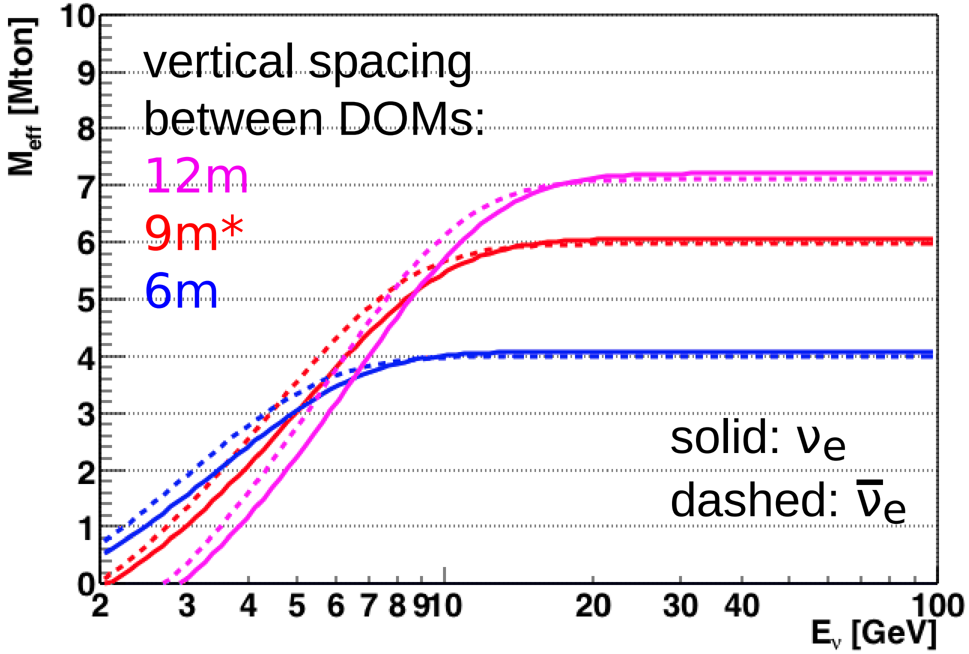
Mass Hierarchy Experimental Signature



- Both muon & electron channel contribute to MH asymmetry
- Electron channel more robust against resolution effects

Detector Response

Effective mass



- Energy threshold determined by DOM spacing

* optimisation study → 9m

9m: Events/yr:
ν_eCC: 17,300
ν_μCC: 24,800
ν_τCC: 3,100
NC: 5,300

Detector resolutions

- Energy resolution:

  $\sigma_E / E_\nu \sim 25\%$ @ 10GeV

- Zenith-angle resolution:

  median $\theta_\nu \sim 5°$ @ 10GeV
  (dominated by kinematic
  ν-lepton scattering angle)

- Event classification:

  90% (70%) correct classification of ν_e^{CC} (ν_μ^{CC}) @ 10GeV

- Few percent atmospheric muon contamination

→ details in LoI
J. Phys. G43 (2016) no.8, 084001

Sensitivity to Mass Hierarchy

- Method:
  - log-likelihood ratio test
  - include systematics

    (overall normalisation, energy scale,

    $\bar{\nu}/\nu$ skew, μ/e skew, NC scaling)

- **3σ MH sensitivity in 3 years**

- Value of δ_{CP} has small but non-negligible impact on sensitivity

- Best case scenario (NH, θ_{23}=48°) could achieve 5σ by mid 2021 (1.5 years)

→ details in LoI

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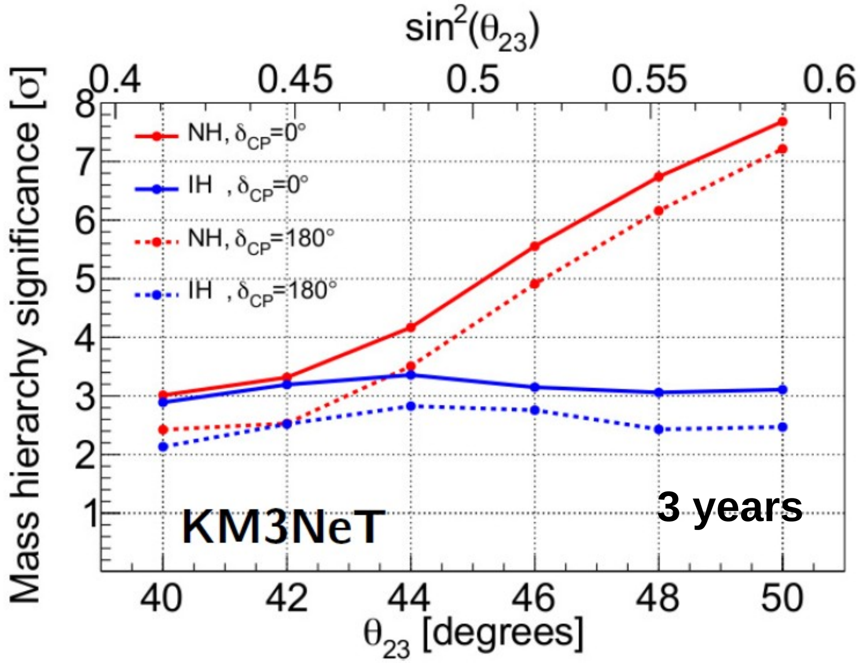
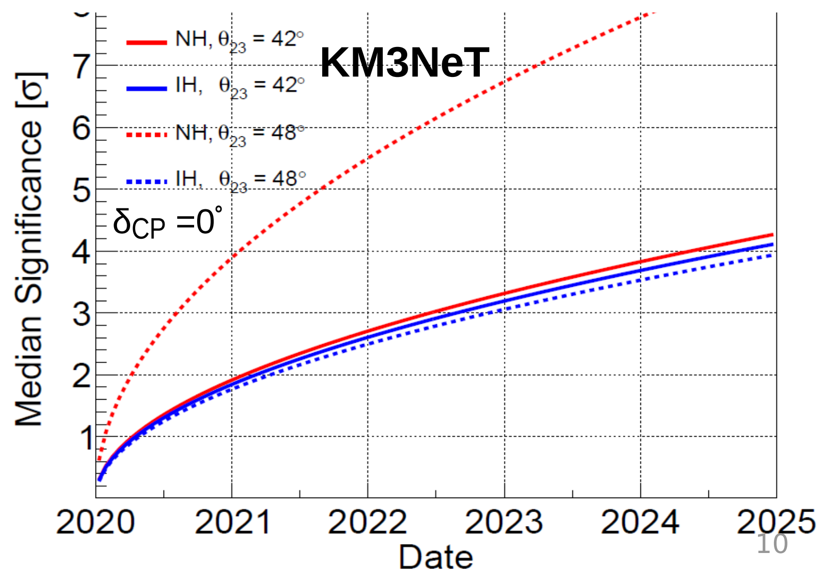
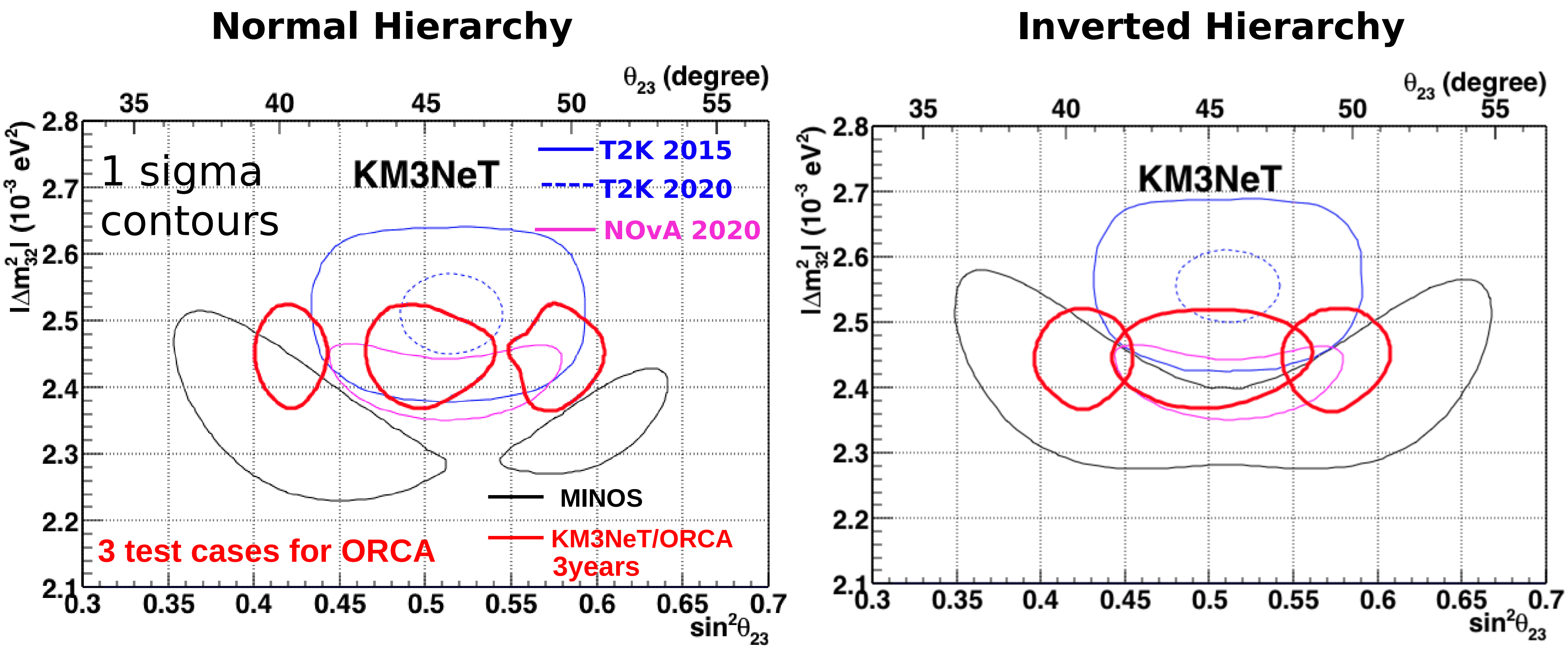




Sensitivity to $|\Delta m^2_{32}|$ and $\sin^2\theta_{23}$

- 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



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Additional ORCA Science Topics

- Unitarity test of neutrino mixing matrix (ν_τ appearance)
- Non-standard interactions, sterile neutrinos and other exotic physics
- Indirect search for dark matter
- Low-energy neutrino astrophysics
- Earth tomography and composition
- Neutrino beam from Protvino (in Russa) to ORCA
  → MH (and δ_{CP}) ☛ J. Brunner, arXiv:1304.6230
- KM3NeT: Earth and Sea science
  → oceanography, seismology, bioacoustics, bioluminescence

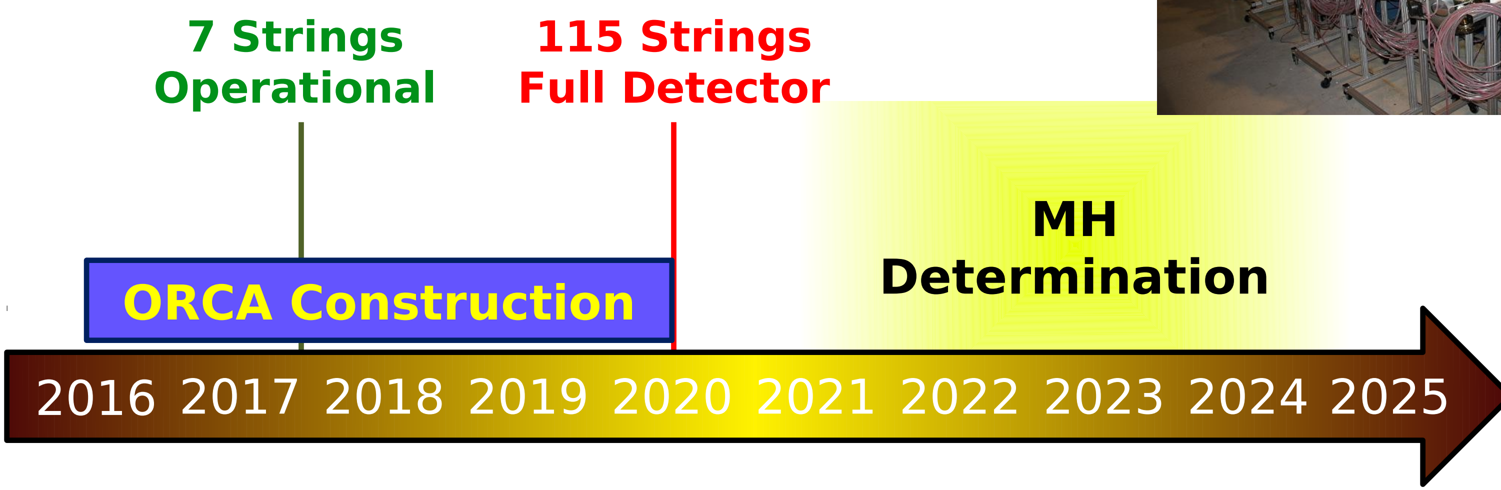
ORCA Construction in Progress

- Phase 1 (funded):

  7-string array at KM3NeT-Fr site
  to demonstrate technology and
  neutrino detection method in few-GeV range

- Phase 2.0 (additional ~40M€, funding requests ongoing):

  deploy full building block with 115 strings



Summary and Perspectives

- KM3NeT: phased construction of a next-generation neutrino detector (ARCA: high energy & ORCA: low energy)

  Letter of Intent ☛ J.Phys G43 (2016) no.8, 084001

- ORCA: underwater Cherenkov detector optimised for few-GeV atmospheric neutrinos to determine neutrino mass hierarchy

- Construction of 7-string demonstrator started (KM3NeT phase 1)
- Depending on funding, completion of 115-string ORCA by 2020 feasible

- With ORCA, 3σ mass hierarchy sensitivity in 3 years feasible (2023)

  → faster than other planned experiments
- With ORCA, competitive measurements of Δm^2_{32} and $\sin^2\theta_{23}$ and rich additional science program