KM3NeT/ORCA: measuring neutrino oscillations and the Mass Hierarchy in the Mediterranean

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on behalf of the KM3NeT Collaboration

XXVI International Workshop on Weak Interactions and Neutrinos

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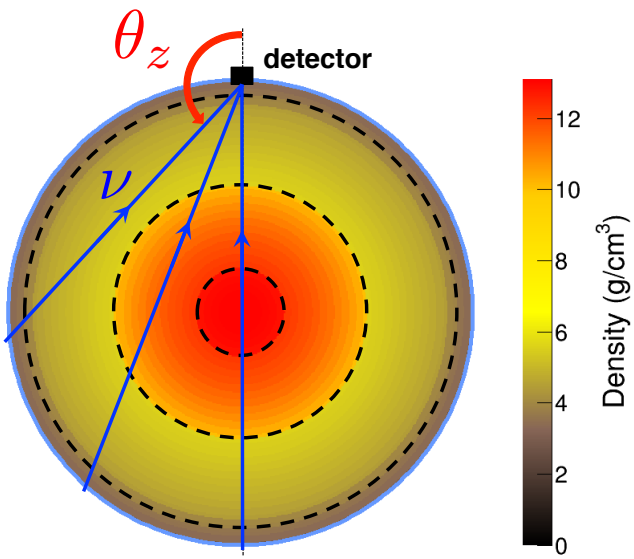
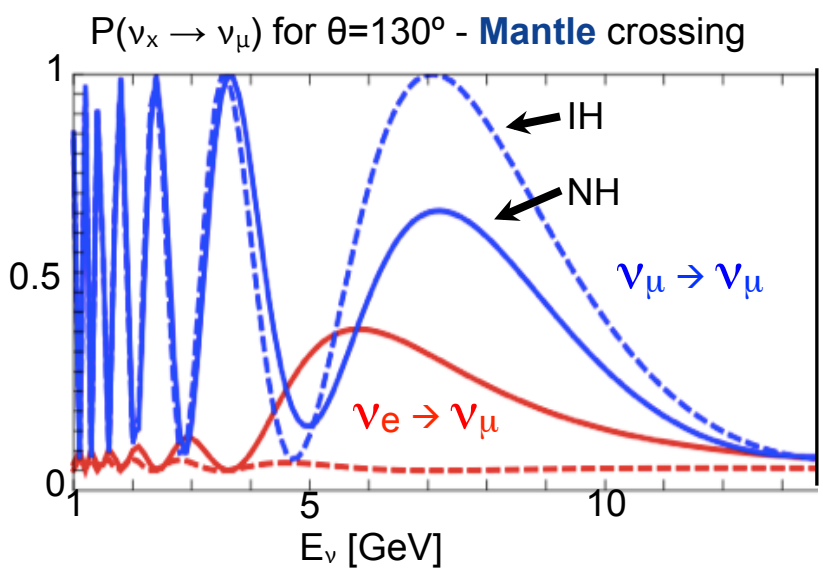
KM3NeT objectives

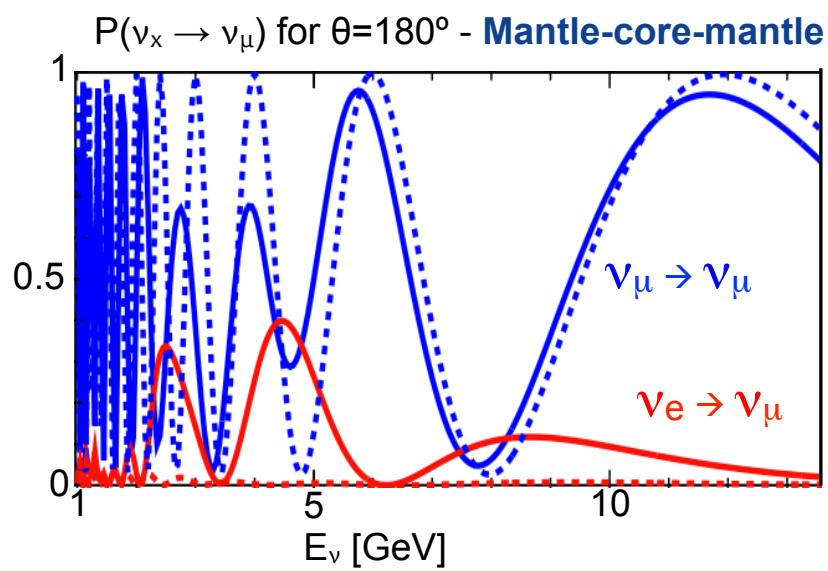
- **ARCA**: Discover/Observe **high-energy neutrino sources** in the Universe

  → **talk by A. Capone Wed. 21 (astroparticle session)**

- **ORCA**: Study ν properties, determine the **Neutrino Mass Hierarchy** and measure oscillation parameters

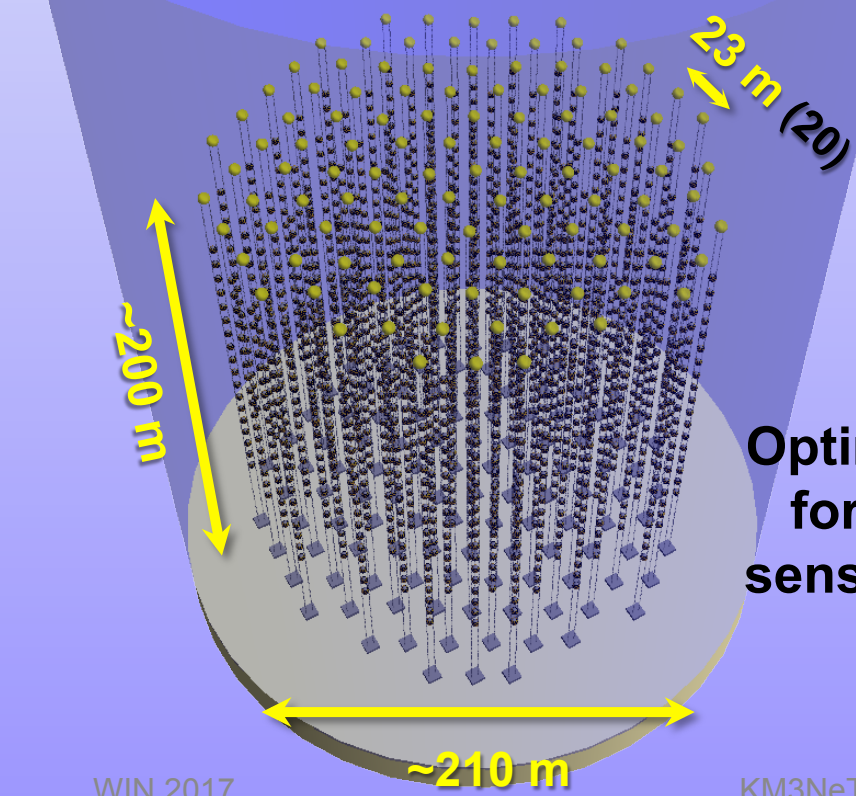


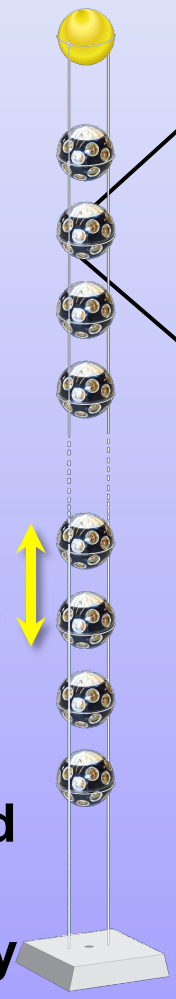




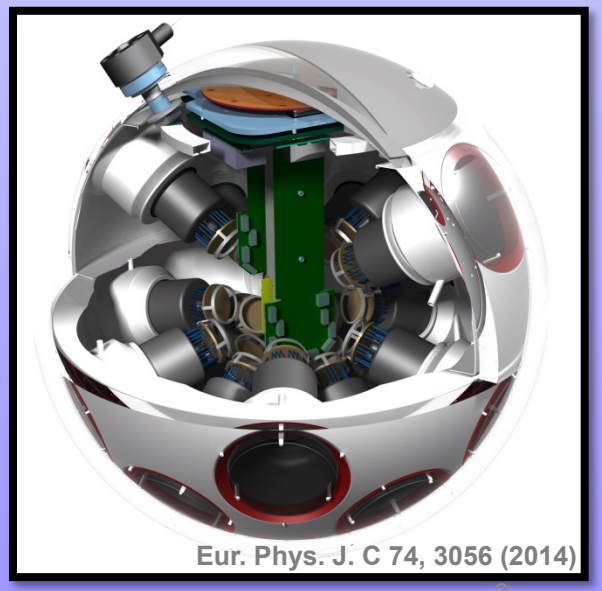
The ORCA detector

- **115** strings
- **18** DOMs / str
- **31** PMTs / DOM
- Total: **64k PMTs**
- **~8 Mton** instrumented **(5.7)**





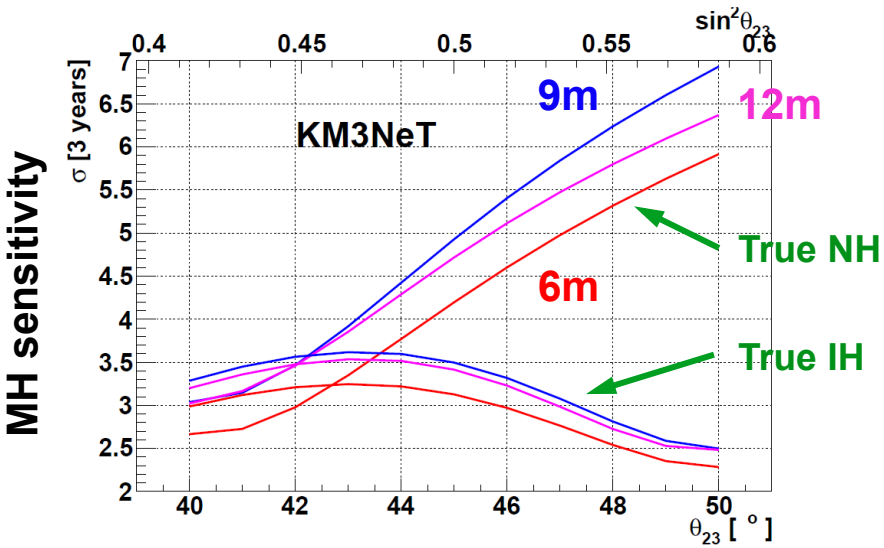
Optimized for MH sensitivity

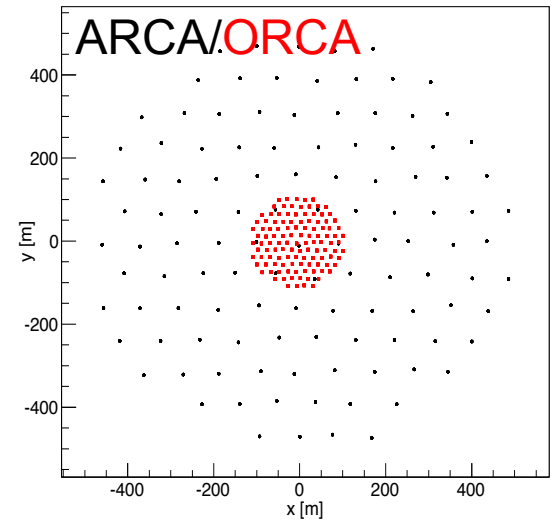


Detector geometry

- Vertical spacing optimized for NMH

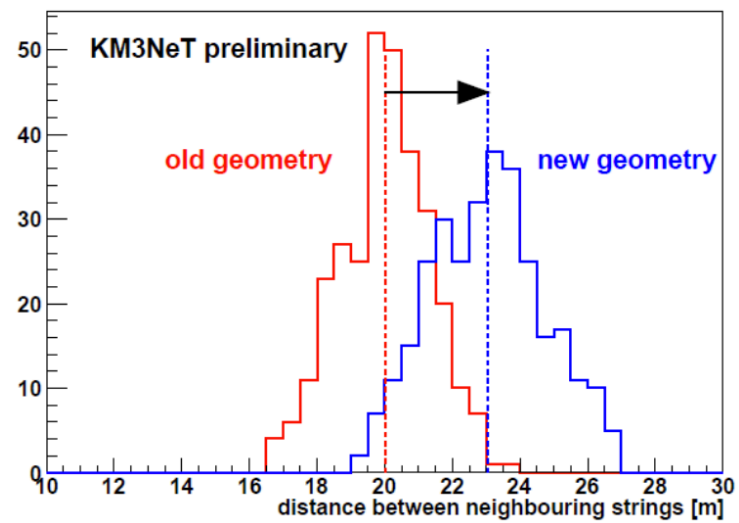
KM3NeT LoI: J. Phys. G 43 (2016) 0840 (1601.07459)



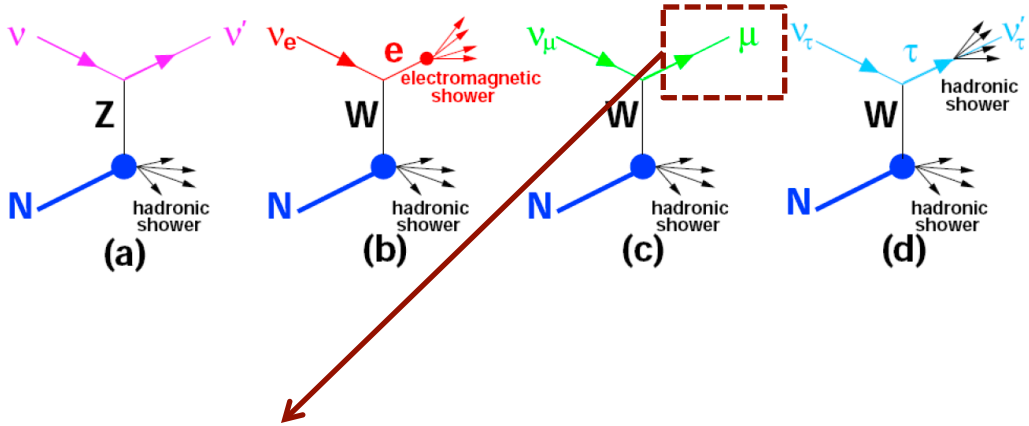


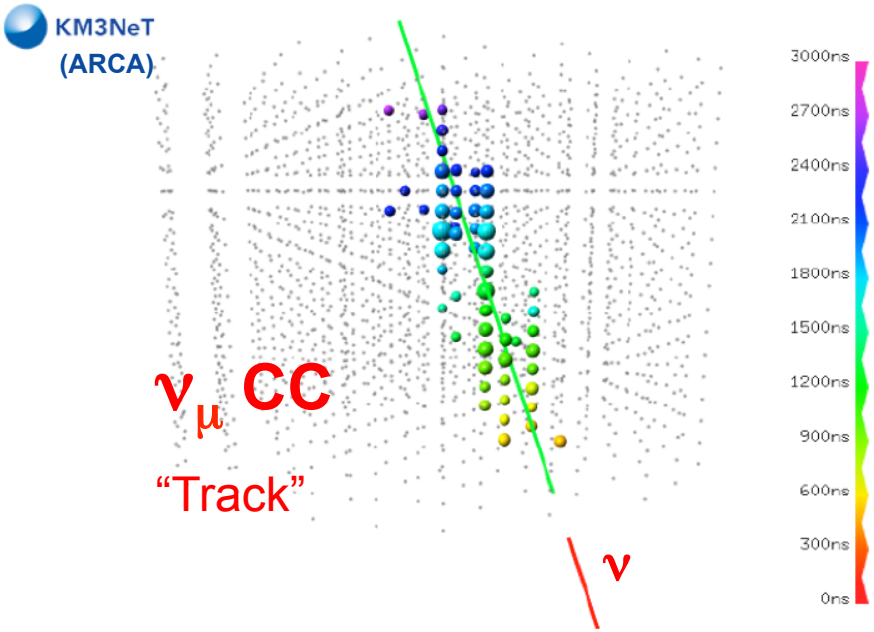
- Horizontal spacing adjusted to deployment requirements

➔ <u>new</u> full MC simulation

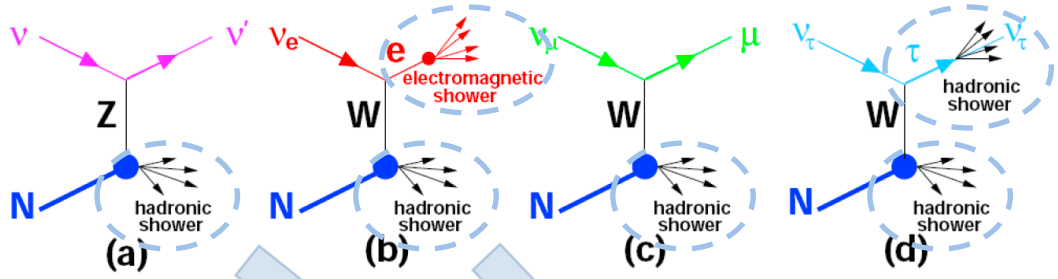


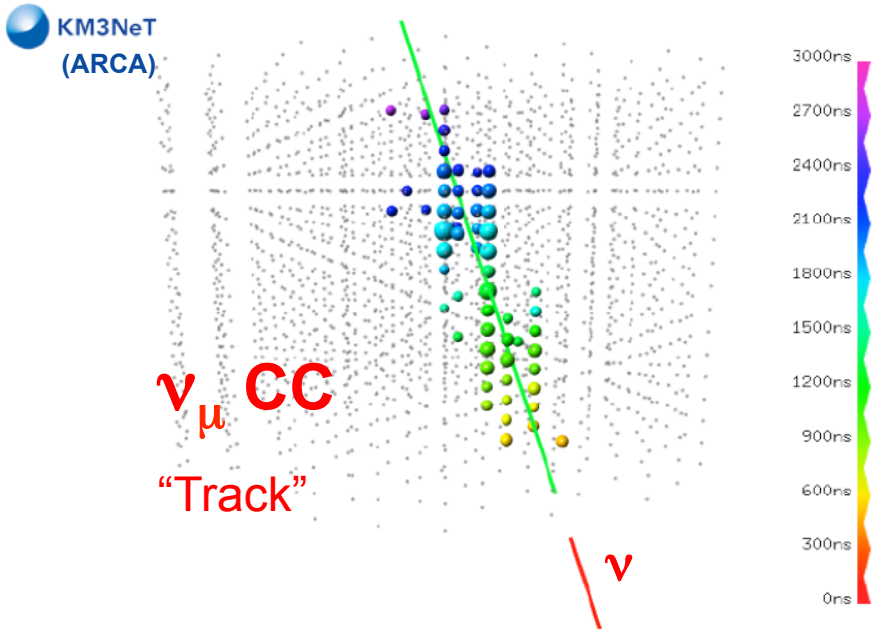
Event topologies: tracks

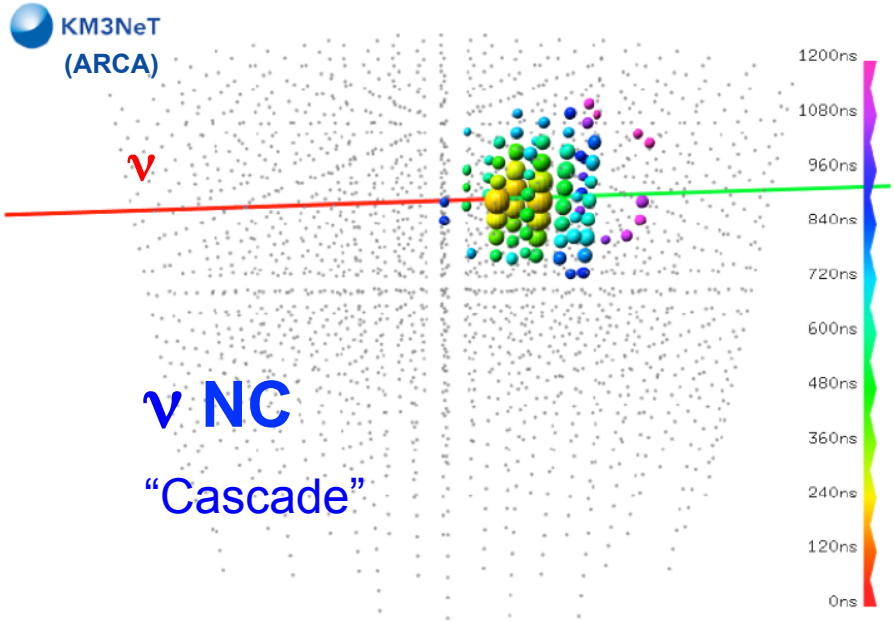




Event topologies: cascades



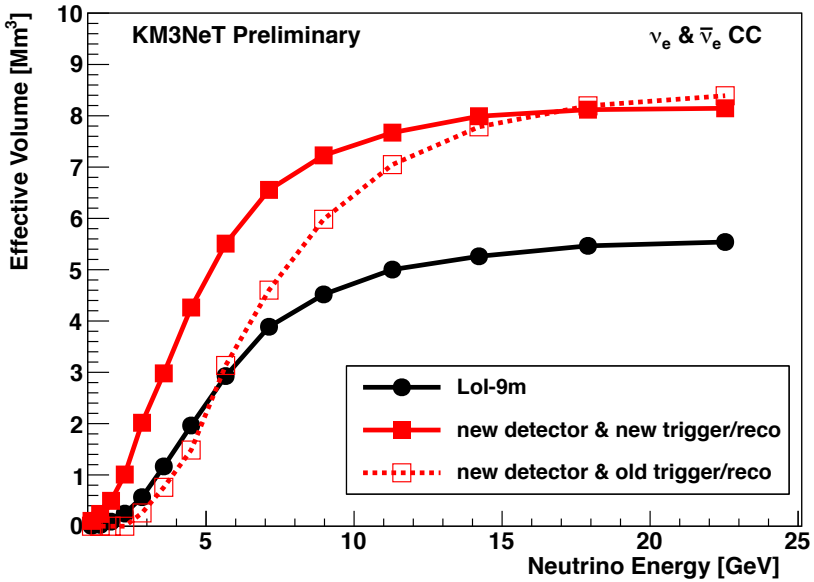




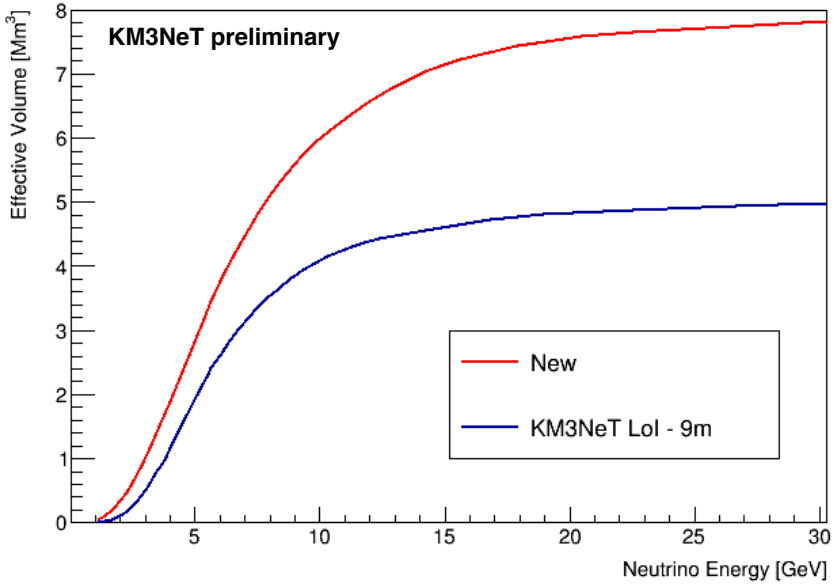
Updated performance: effective volume

- New loosened trigger ➔ increase of low-E efficiency
- Adapted & improved both Track and Shower reconstructions
- Particle ID model being refined
- NMH & oscillation sensitivities <u>not yet updated</u> with these improvements

electron channel



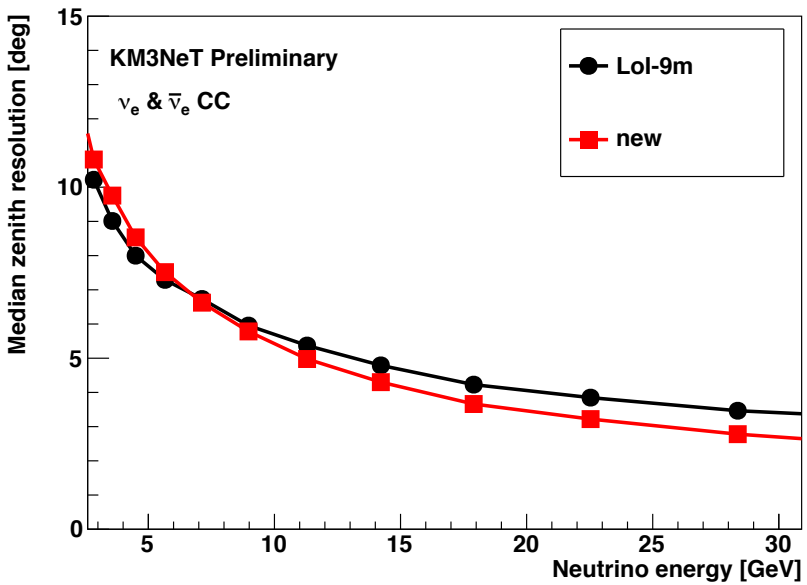
muon channel



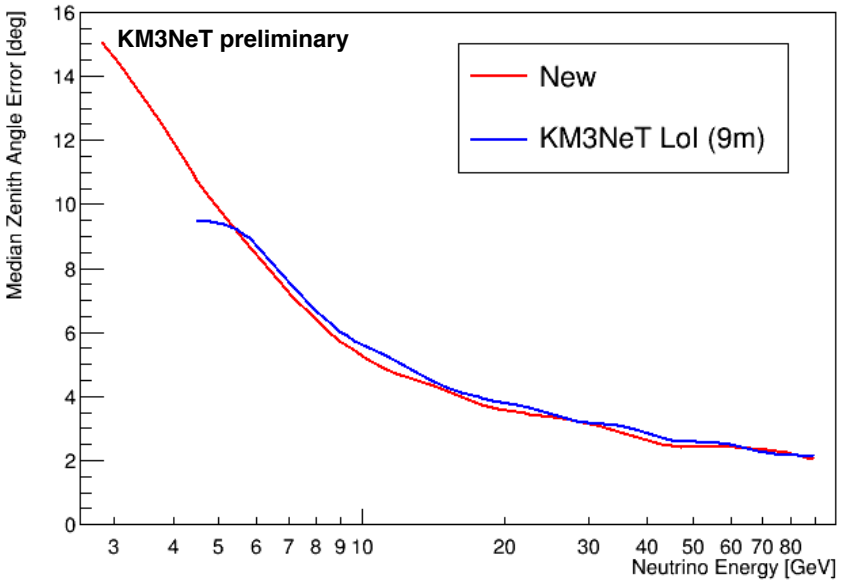
Updated performance: zenith resolution

- New loosened trigger ➔ increase of low-E efficiency
- Adapted & improved both Track and Shower reconstructions
- Particle ID model being refined
- NMH & oscillation sensitivities <u>not yet updated</u> with these improvements

electron channel



muon channel



Statistical analysis

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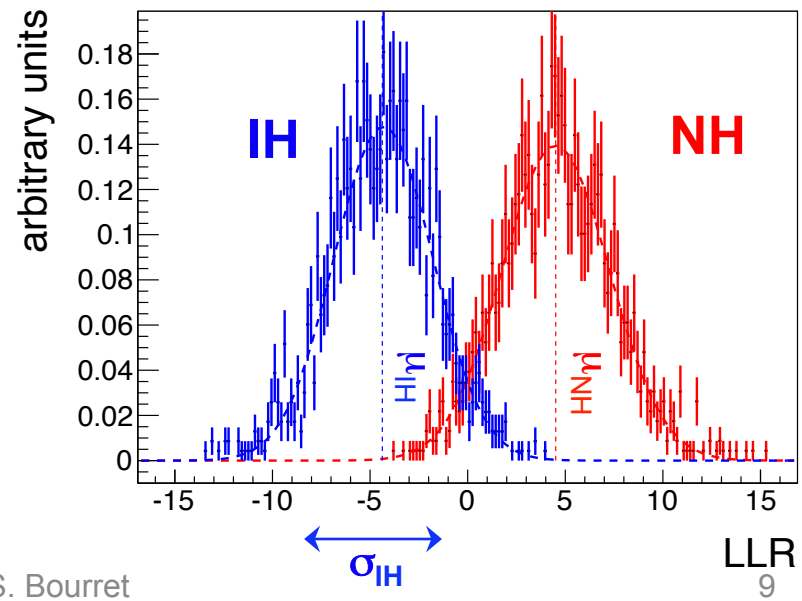
parameter	*true value distr.*	*initial value/prior distr.*	*treatment*	*prior*
θ_{23} [°]	$\{40, 42, \ldots, 50\}$	uniform over $[35, 55]$	fitted	no
θ_{13} [°]	8.42	$\mu = 8.42$, $\sigma = 0.26$	fitted	yes
θ_{12} [°]	34	$\mu = 34$, $\sigma = 1$	fluct.*	N/A
ΔM^2 [10^{-3} eV^2]	$\mu = 2.4$, $\sigma = 0.05$	$\mu = 2.4$, $\sigma = 0.05$	fitted	no
Δm^2 [10^{-5} eV^2]	7.6	$\mu = 7.6$, $\sigma = 0.2$	fluct.*	N/A
δ_{CP} [°]	{0, ..., 360}	uniform over $[0, 360]$	fitted	no
overall flux factor	1	$\mu = 1$, $\sigma = 0.1$	fitted	yes
NC scaling	1	$\mu = 1$, $\sigma = 0.05$	fitted	yes
$\nu/\bar{\nu}$ skew	0	$\mu = 0$, $\sigma = 0.03$	fitted	yes
μ/e skew	0	$\mu = 0$, $\sigma = 0.05$	fitted	yes
energy slope	0	$\mu = 0$, $\sigma = 0.05$	fitted	yes

Table 1: Default parameter settings used for the LLR analysis. For θ_{23} a total of seven initial values is tried: $x + i \times 5°$, where x is the randomly drawn value and $i \in [-3, -2, \ldots, 3]$. *$\theta_{12}$ and δm^2 are assigned a fixed value in the fit, randomly drawn from the initial value distribution.

- Profile over 4 oscillation & 5 syst. parameters

$$S_{\mathrm{NH}} = \frac{\mu_{\mathrm{NH}} - \mu_{\mathrm{IH}}}{\sigma_{\mathrm{IH}}}$$

- Generate pseudo-experiments and compute $\mathrm{LLR} = \log\left(\mathcal{L}_{\mathrm{NH}}/\mathcal{L}_{\mathrm{IH}}\right)$
- **Median sensitivity** ⇔ probability of observing median LLR of wrong hierarchy



Sensitivity results (LoI detector)

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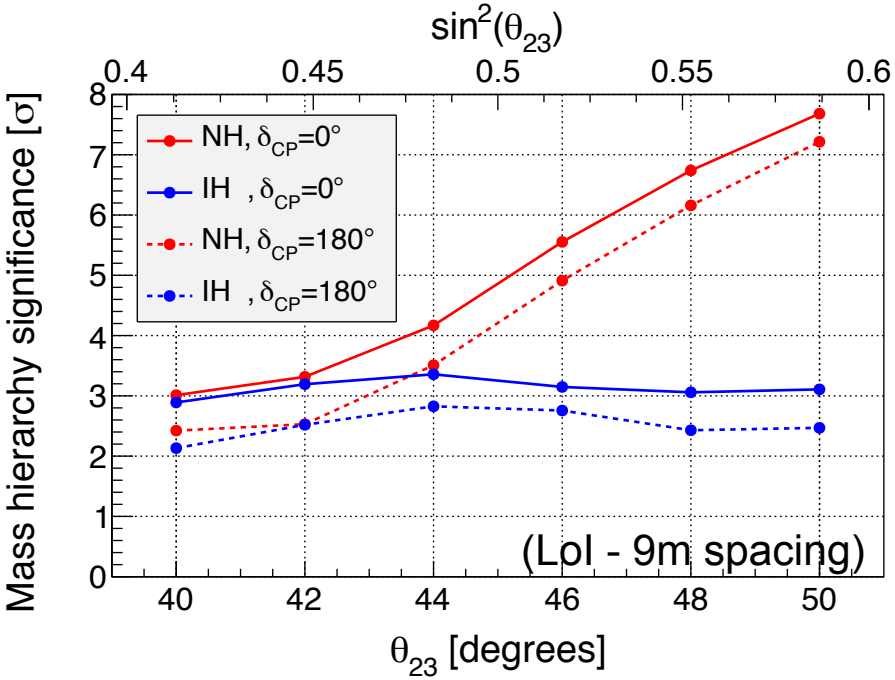
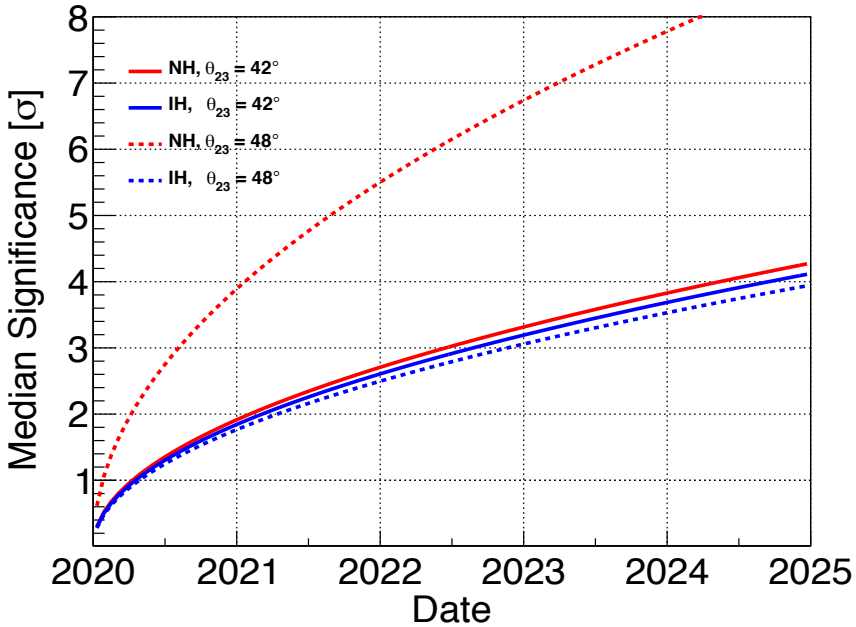


- **~ 3σ** MH sensitivity **in 3 years**
- The true value of δ_{cp} has small but non-negligible impact

- The combination of **NH and upper octant** of θ_{23} would significantly improve sensitivity (**5σ in 3 years**)
- In the IH, sensitivity is mostly independent of octant of θ_{23}



Oscillation parameters measurement

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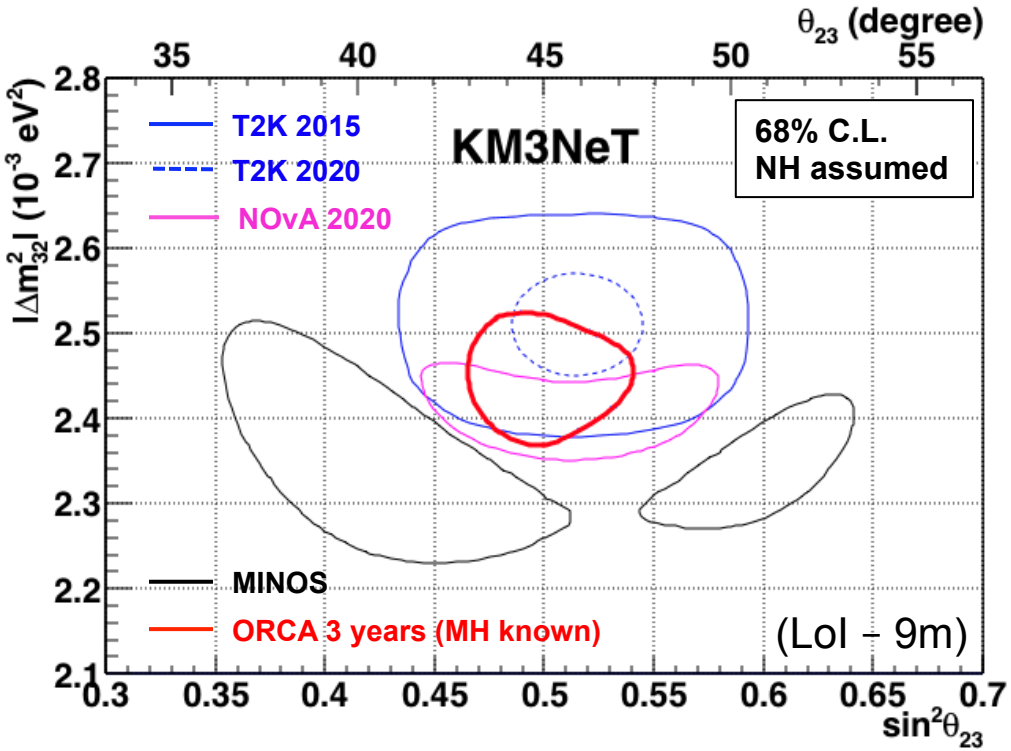
- Achieve **2-3%** prec. in Δm^2_{32} and **4-10%** in $\sin^2\theta_{23}$ (3 years)
- **Competitive with LBL experiments** projected sensitivity in 2020
- Early determination of the octant of θ_{23} is feasible



NH, δ_{CP} = 0, maximal mixing assumed

- Analysis based on Asimov datasets
- θ_{12}, θ_{13} and δm^2 fixed
- Other param. **unconstrained**

- **Energy scale** uncertainty added (has **no impact** on NMH sens.)

Oscillation parameters measurement

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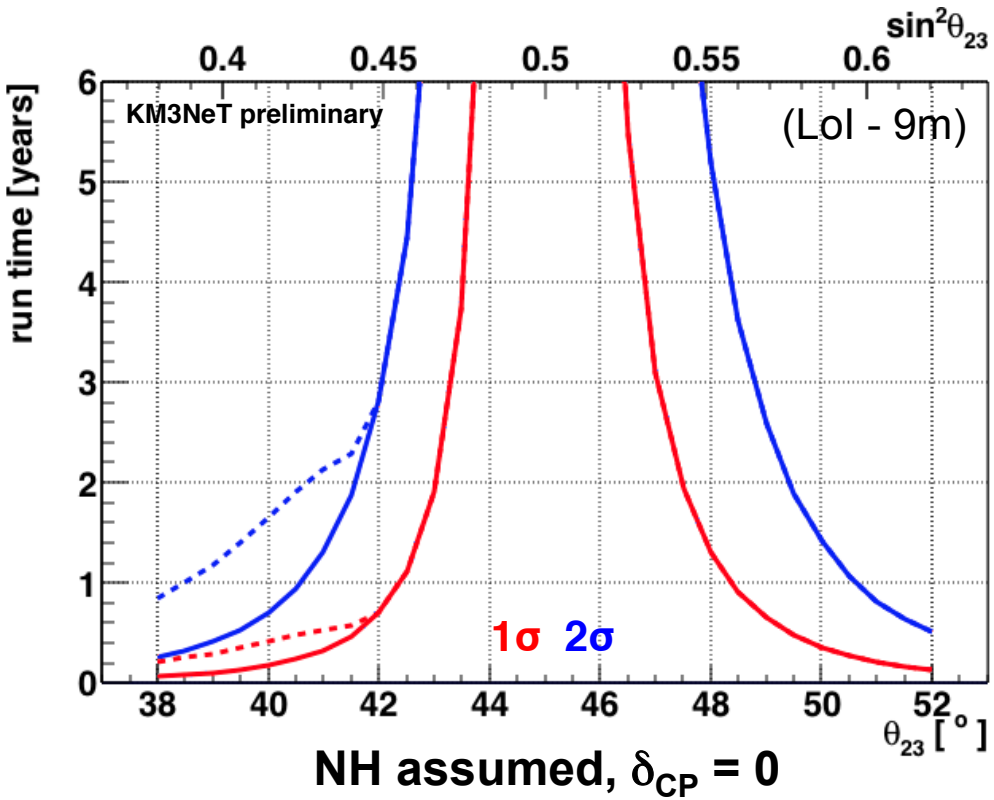

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- θ_{12}, θ_{13} and δm^2 fixed
- Other param. **unconstrained**

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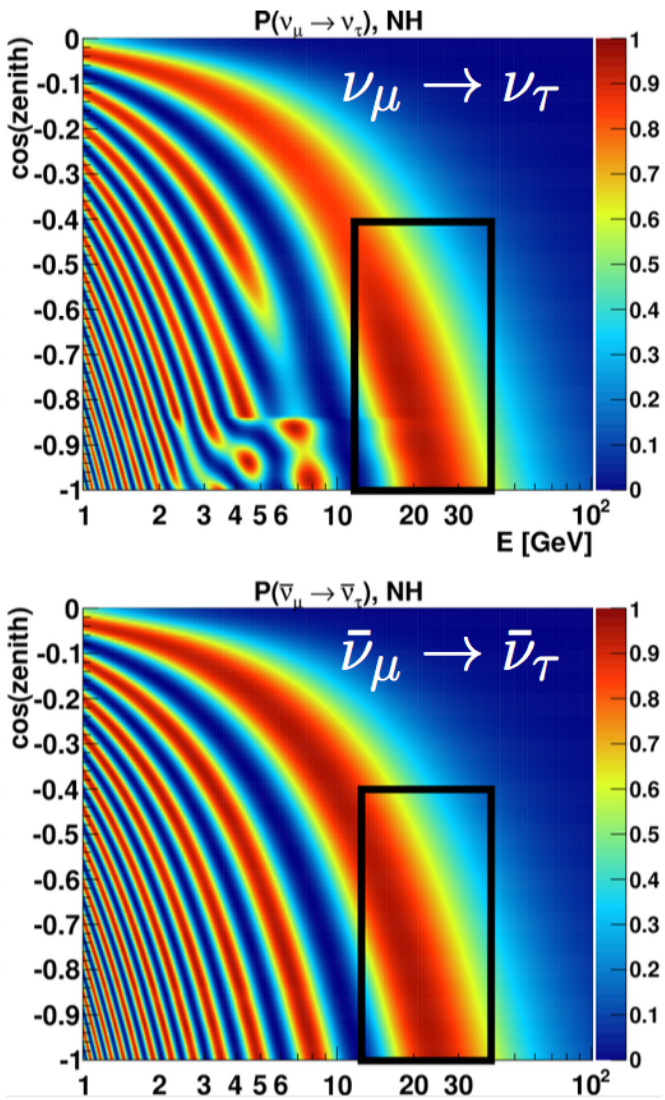
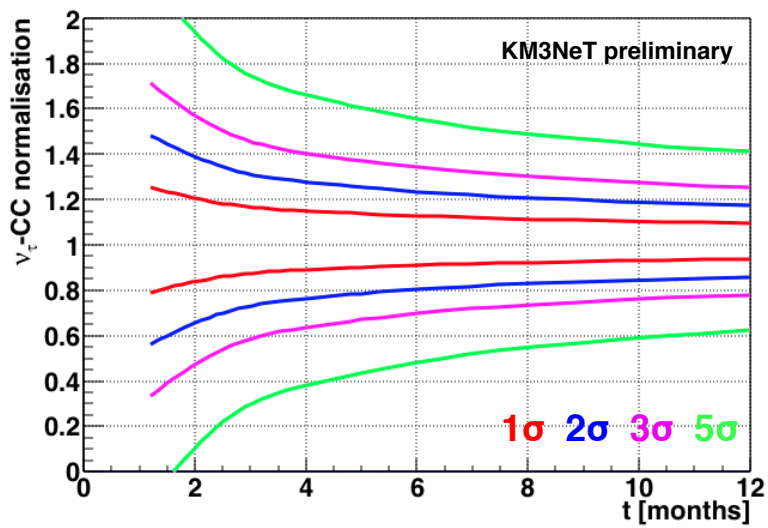
—— **MH known**

--- **MH unknown**

Tau neutrino appearance



- ν_τ appearance tests PMNS unitarity and BSM theories
- ~ 3k ν_τ CC events/year with full ORCA
- Rate constrained within ~10% in 1 year
- Sensitivity with few strings is under study



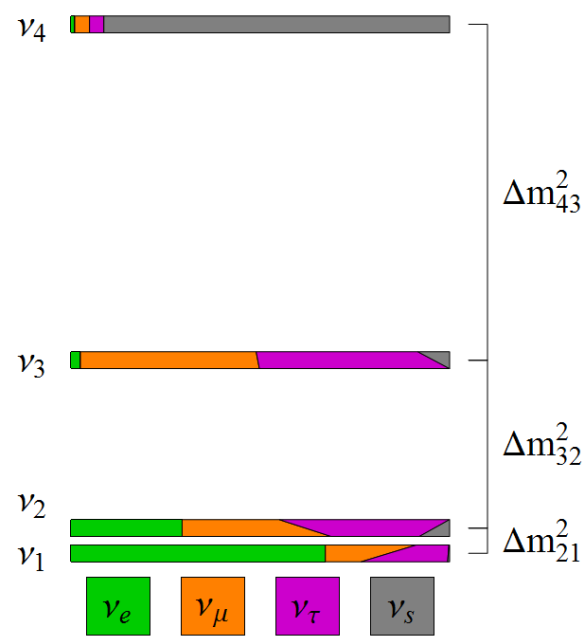
← unitarity

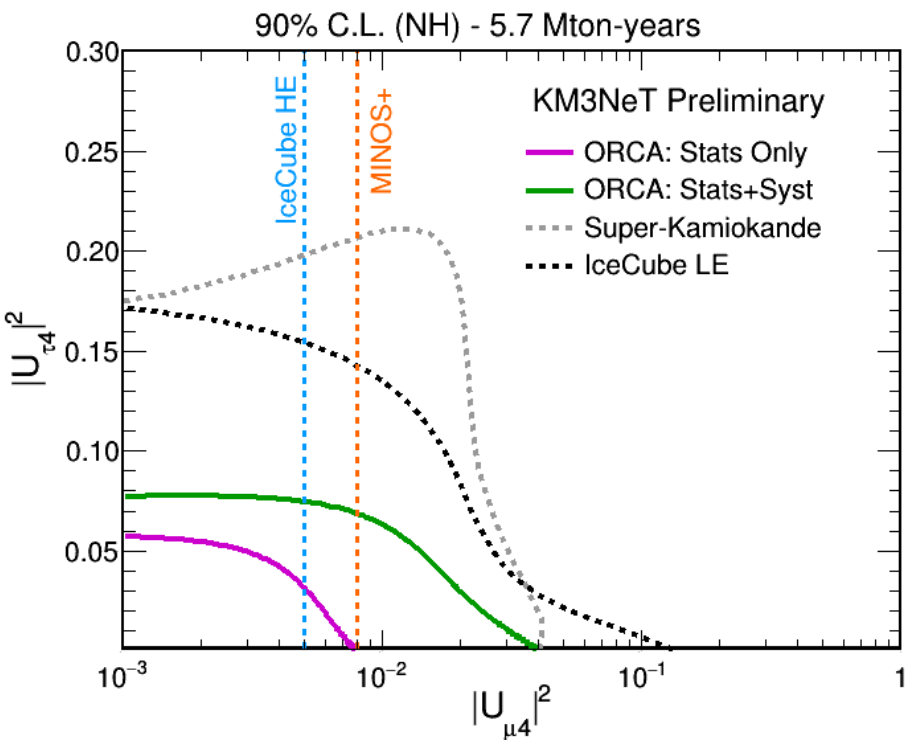
← no appearance

- analysis uses same PID as NMH (not optimised for ν_τ)
- prior on NC norm. (30%) and $\nu/\bar{\nu}$ skew (10%)

Light sterile neutrino

- The dominant effect in ORCA of adding a eV scale sterile neutrino would be the **suppression of $\nu_\mu \rightarrow \nu_\tau$ oscillation** at ~20 GeV
- With 1 year of data ORCA is sensitive to $|U_{\tau 4}|^2$ values smaller than current limits set by SK





- Fitted: 4 syst. + 2 osc. (θ_{23}, ΔM^2)
- $U_{e4} = 0$
- $\Delta m^2_{41} = 0.3\ eV^2$

Non-Standard Interactions

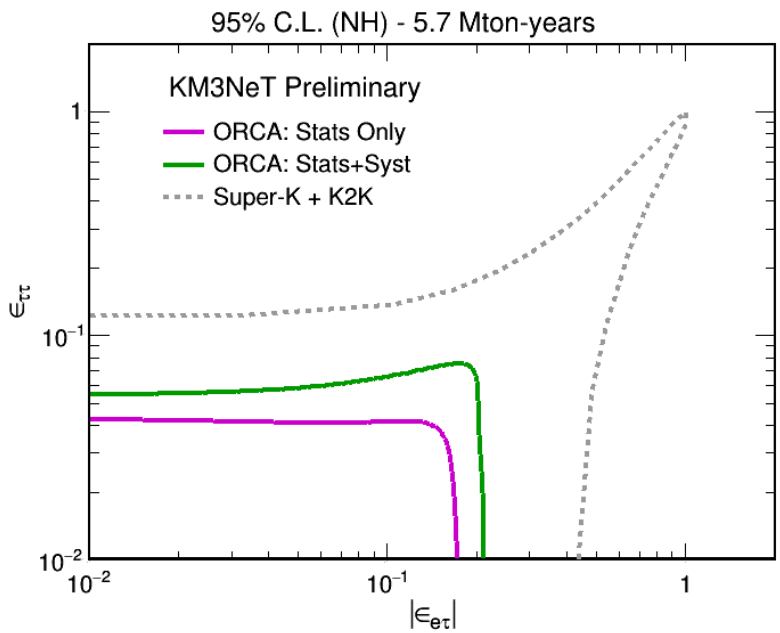
- Current limits:

  → see e.g. talk by I. Mocioiu Tue. 20 (ν session)

$$\begin{pmatrix} |\varepsilon_{ee}| < 4.2 & |\varepsilon_{e\mu}| < 0.33 & |\varepsilon_{e\tau}| < 3.0 \\ & |\varepsilon_{\mu\mu}| < 0.068 & |\varepsilon_{\mu\tau}| < 0.33 \\ & & |\varepsilon_{\tau\tau}| < 21 \end{pmatrix}$$

Rept. Prog. Phys. 76, 044201 (2013)

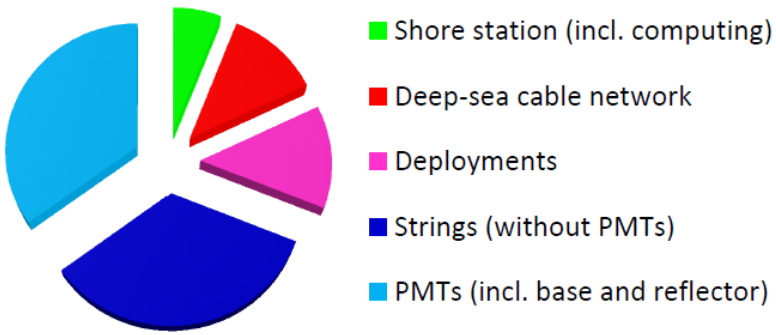
- With only 1 year of data, ORCA sensitive to NSI effects below these limits:



- Fitted: 4 syst. + 2 osc. (θ_{23}, ΔM^2)
- 95% C.L. in ($|\varepsilon_{ee}|$, $|\varepsilon_{e\tau}|$, $|\varepsilon_{\tau\tau}|$) space
  → 2D projection for $|\varepsilon_{ee}| = 0$
- SK + K2K limits from arXiv:0506143

Funding and timeline

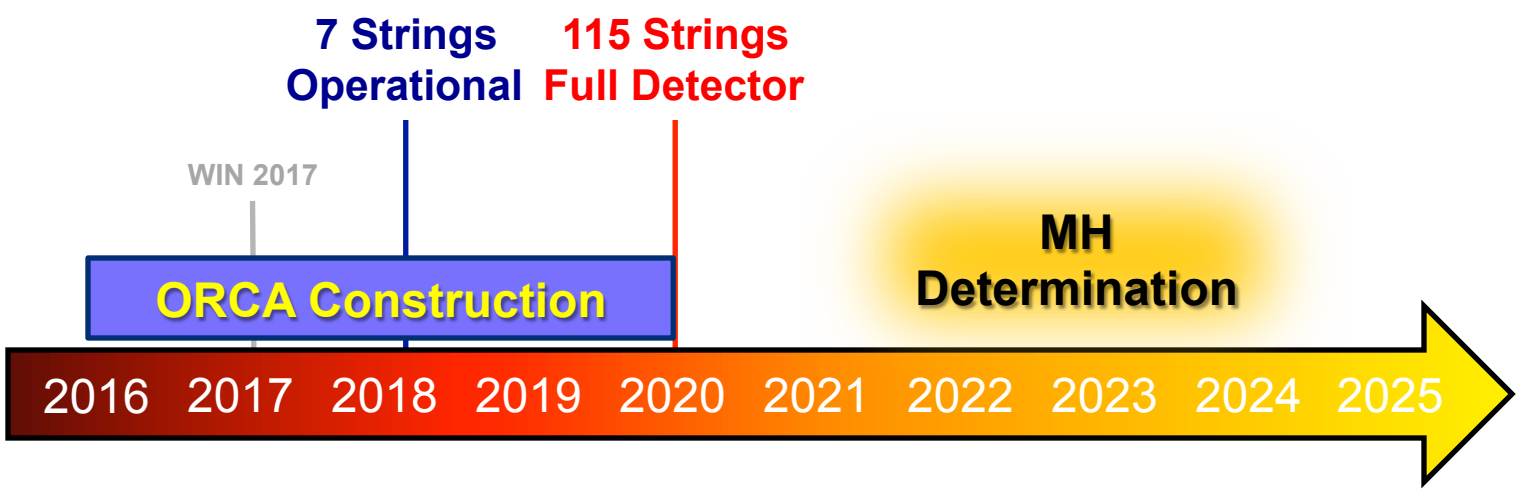
- **7 strings funded** for ORCA (11 M€ inc. infrastructure)
- 2 strings deployment Sept. 17



1st node: Sept 2016

1st ORCA string ready

Total ORCA cost: ~45 M€



Summary

- ORCA is being built in the Mediterranean sea to measure oscillations with atmospheric neutrinos: detector is to be completed by 2020
- Main goal is to determine the **Neutrino Mass Hierarchy**, with a sensitivity of **>3σ** in 3 years of operation
- ORCA will also improve measurements of other oscillation parameters such as Δm^2_{32} and θ_{23}
- Further physics potential: PMNS unitarity, sterile ν's, NSI…
- More topics not adressed in this talk: DM detection, Earth tomography, supernovae…