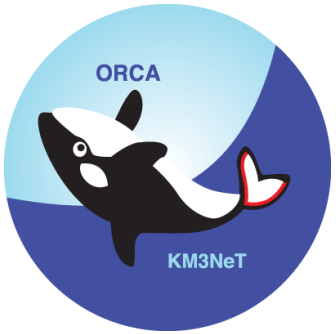
Status and prospects of the KM3NeT-ORCA experiment

João Coelho

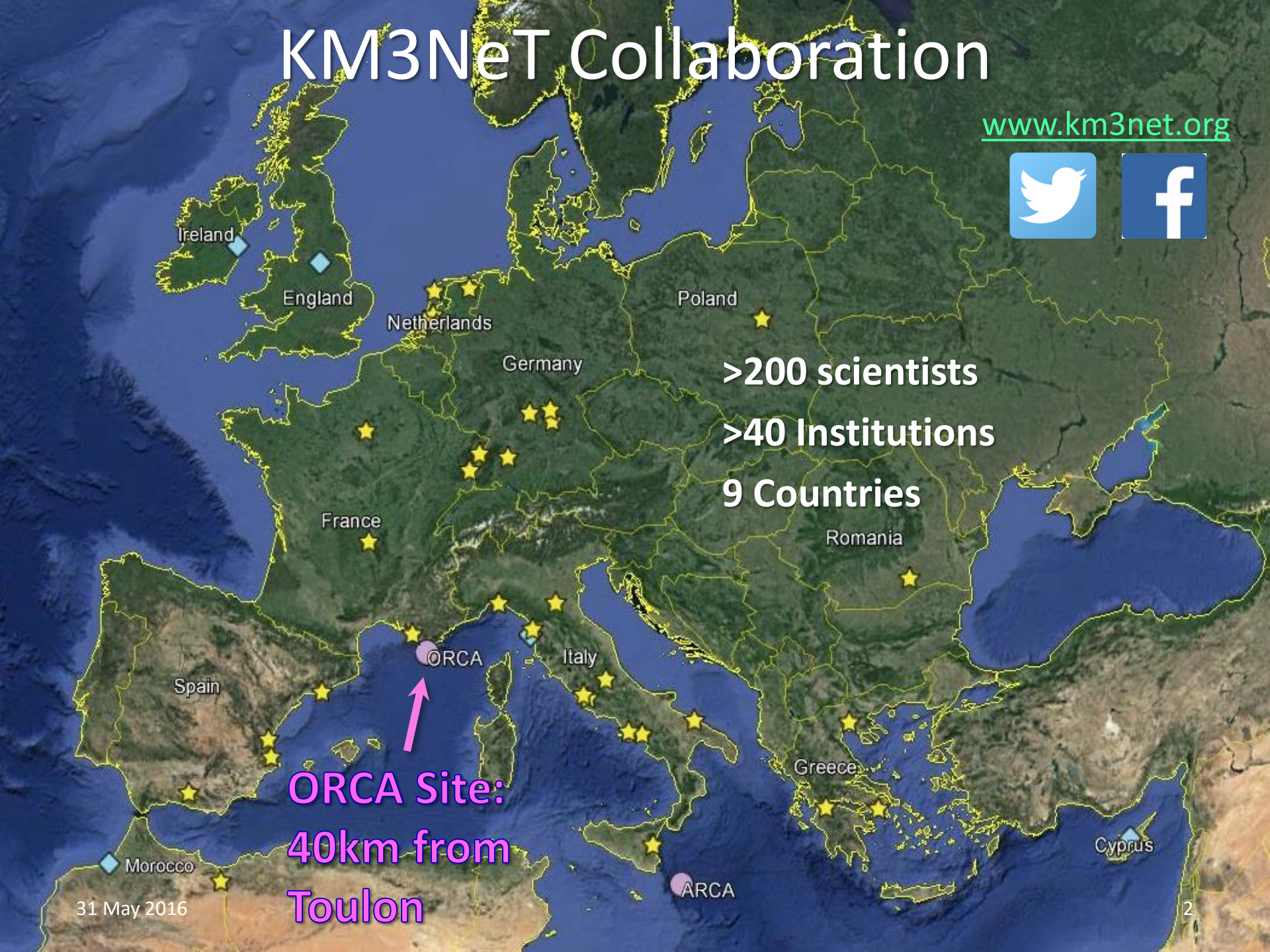
for the KM3NeT Collaboration

31 May 2016



KM3NeT Collaboration

www.km3net.org



>200 scientists

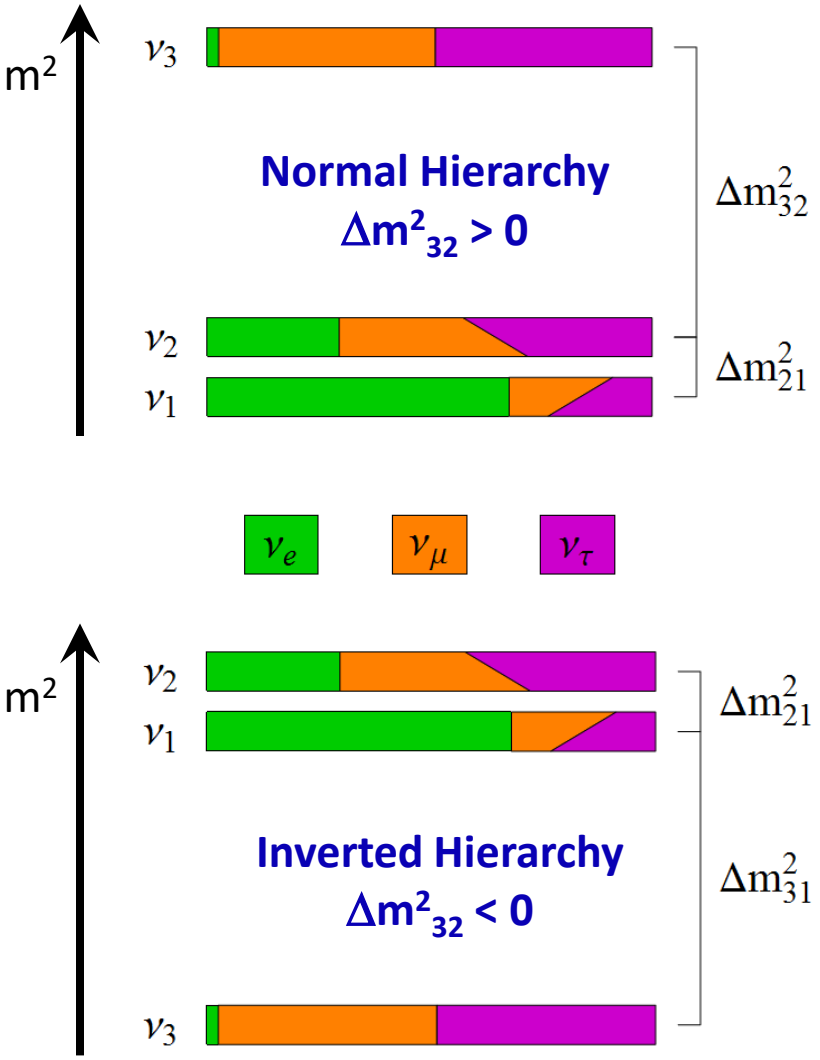
>40 Institutions

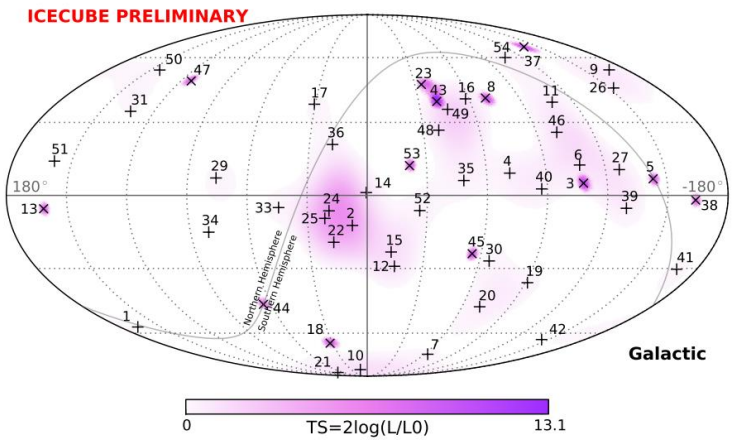
9 Countries

ORCA Site:
40km from
Toulon

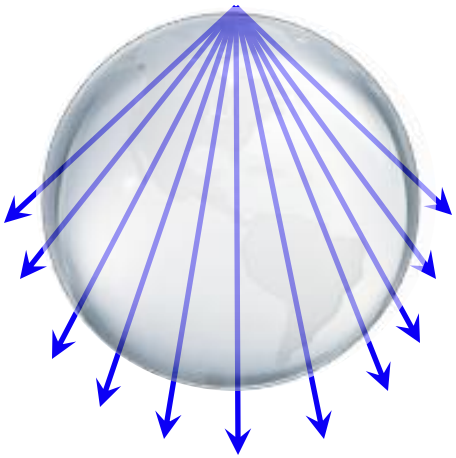
Objectives

- **ORCA**: Determine the **Neutrino Mass Hierarchy (NMH)**
- **ARCA**: Discover/Observe high-energy neutrino sources in the universe (see **Javier**'s talk **tomorrow**)

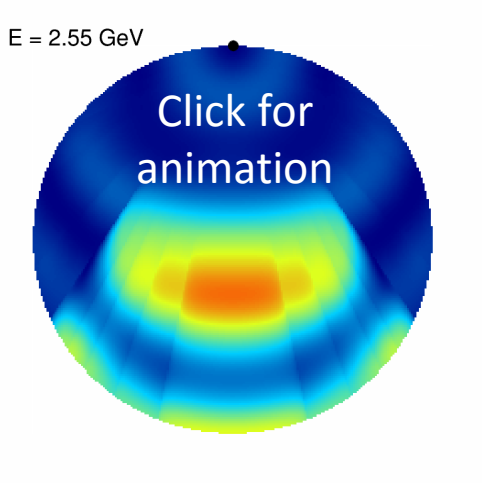




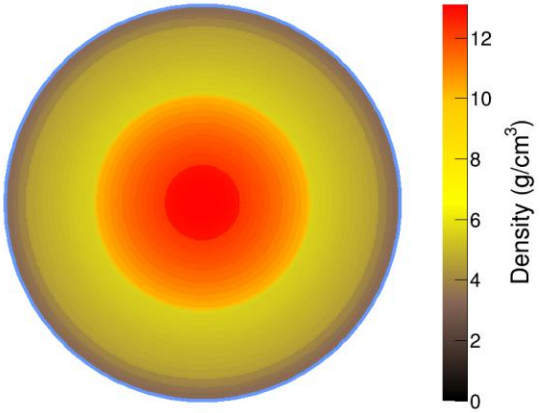
Matter Resonance and MH



Earth is transparent to ν's with a "refractive index"



Oscillations are **resonant** at certain energies



E_{res} ~ 7 GeV in Mantle
E_{res} ~ 3 GeV in Core

Depends on
sign of Δm^2_{32} (MH)

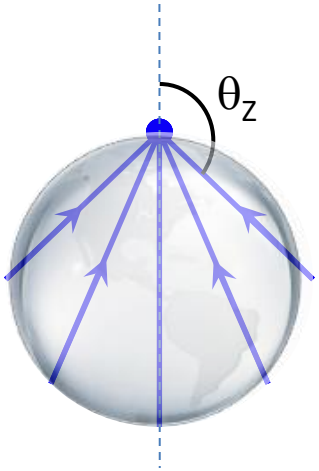
$$\sin^2 2\theta^m_{13} \equiv \sin^2 2\theta_{13} \left(\frac{\Delta m^2_{31}}{\Delta^m m^2} \right)^2$$

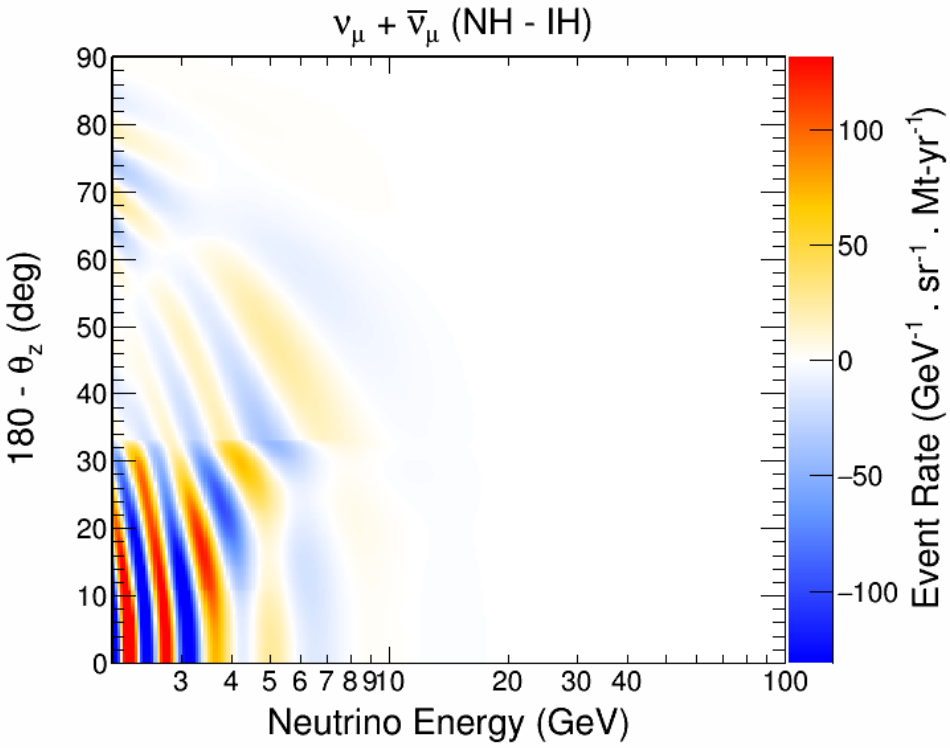
$$\Delta^m m^2 \equiv \sqrt{(\Delta m^2_{31} \cos 2\theta_{13} - 2 E_\nu A)^2 + (\Delta m^2_{31} \sin 2\theta_{13})^2}\,,$$

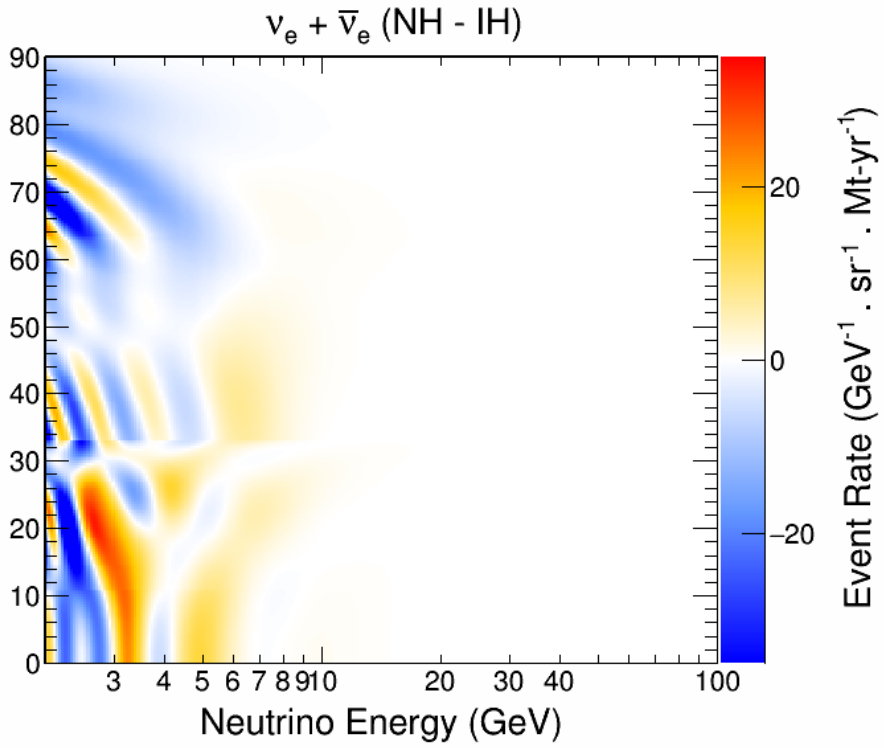
$$E_{\rm res} \equiv \frac{\Delta m^2_{31} \cos 2\theta_{13}}{2\sqrt{2} G_F N_e} \simeq 7\,{\rm GeV} \left(\frac{4.5\,{\rm g/cm^3}}{\rho} \right) \left(\frac{\Delta m^2_{31}}{2.4 \times 10^{-3}\,{\rm eV}^2} \right) \cos 2\theta_{13}\,.$$

How to Measure MH

- Measure neutrino direction and energy
- Search for **oscillation patterns** from **matter effects**
- Requires **large statistics** and good **energy and direction res.**







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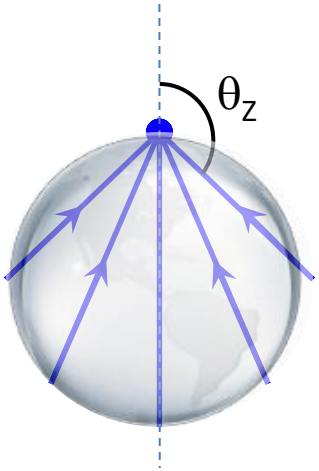

- Measure neutrino direction and energy
- Search for **oscillation patterns** from **matter effects**
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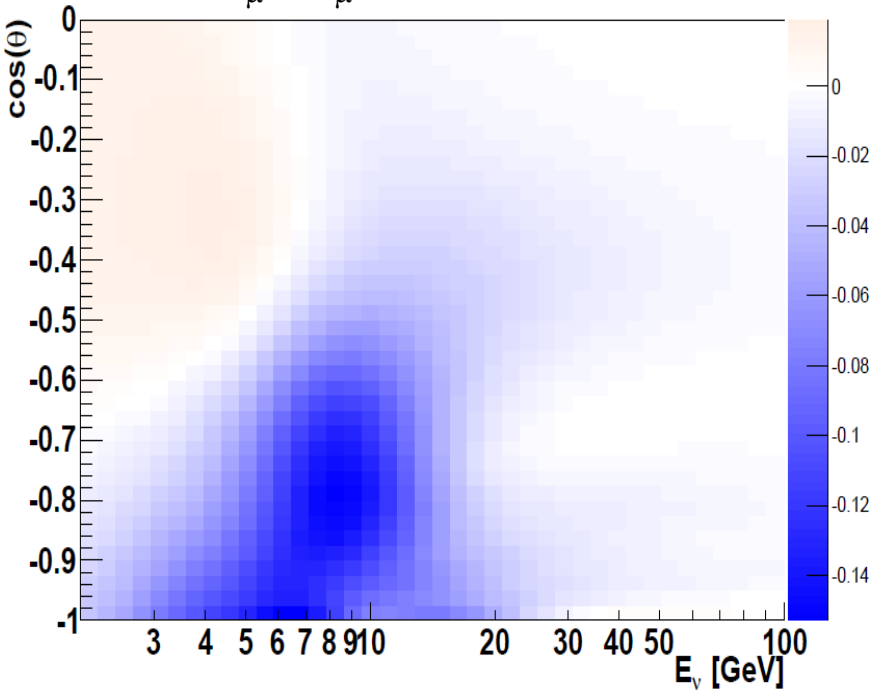
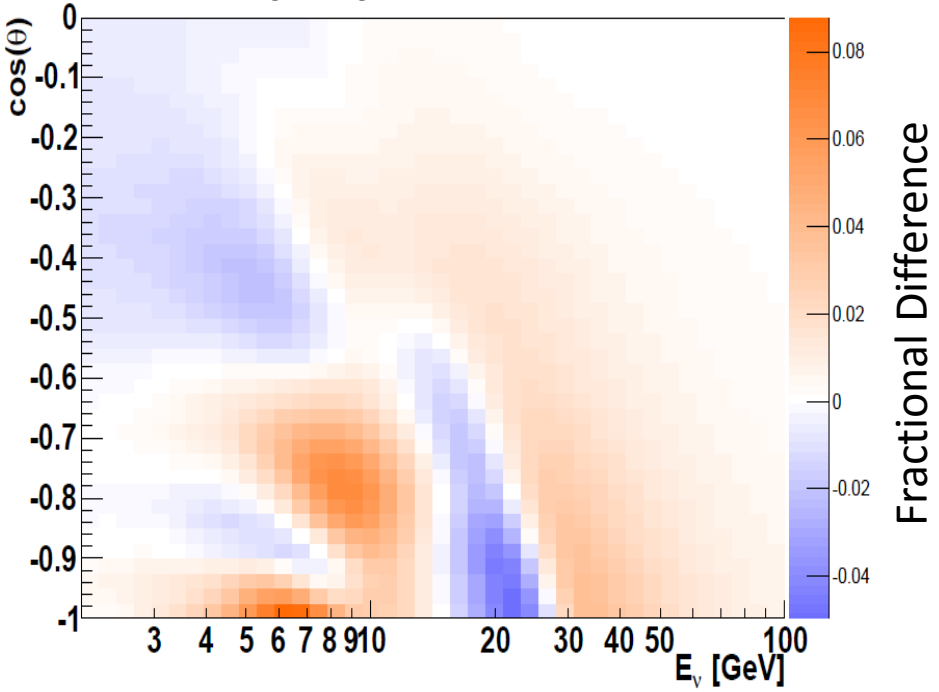
$\nu_\mu + \bar{\nu}_\mu$ (NH - IH) / NH



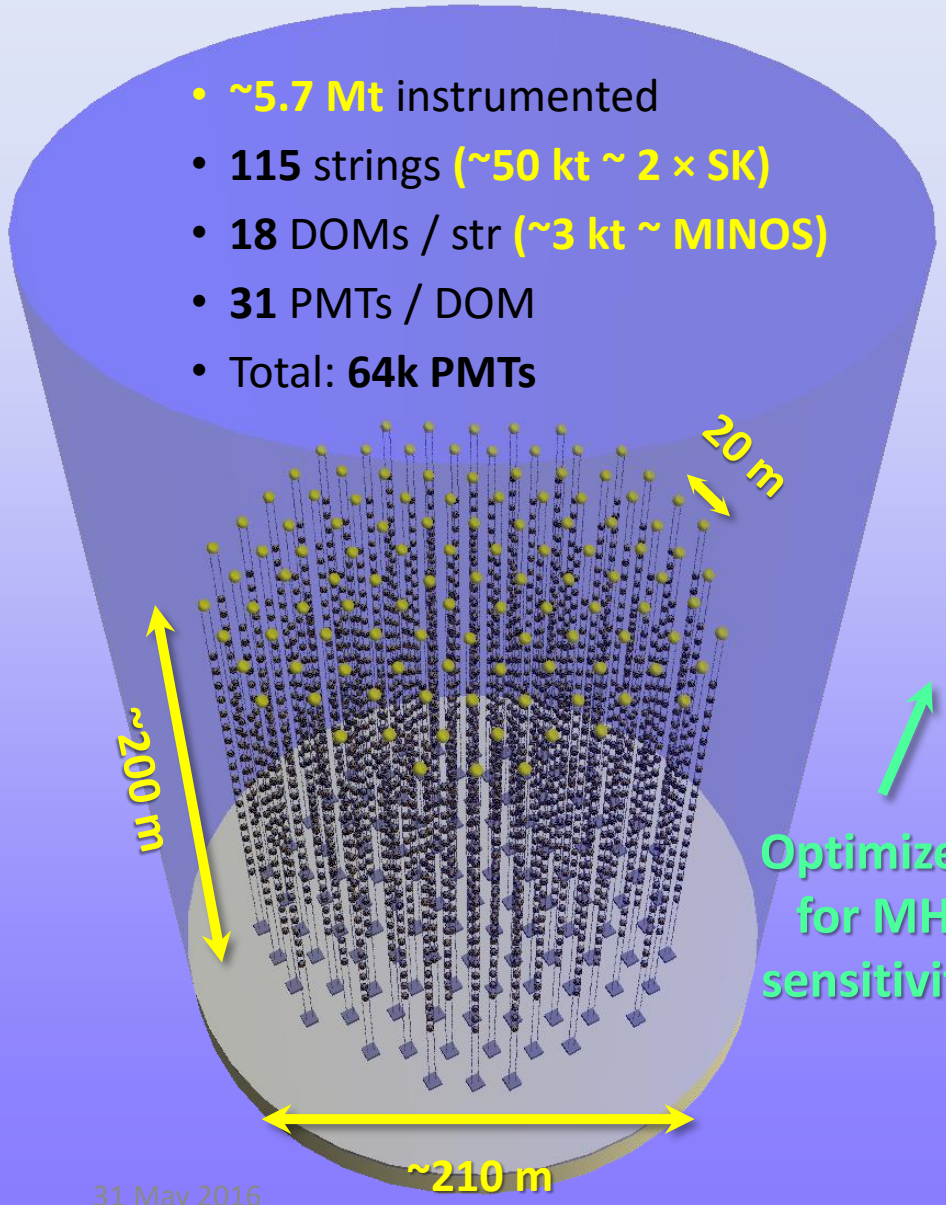
$\nu_e + \bar{\nu}_e$ (NH - IH) / NH

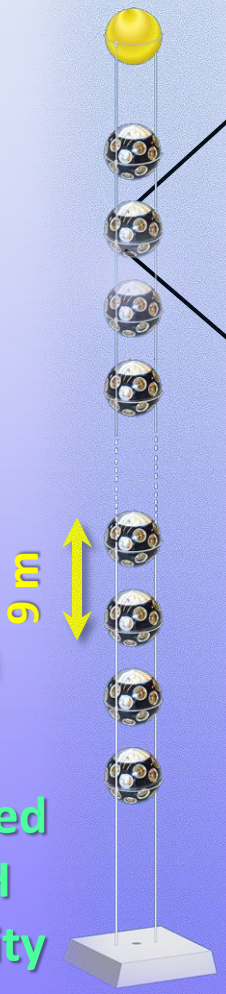


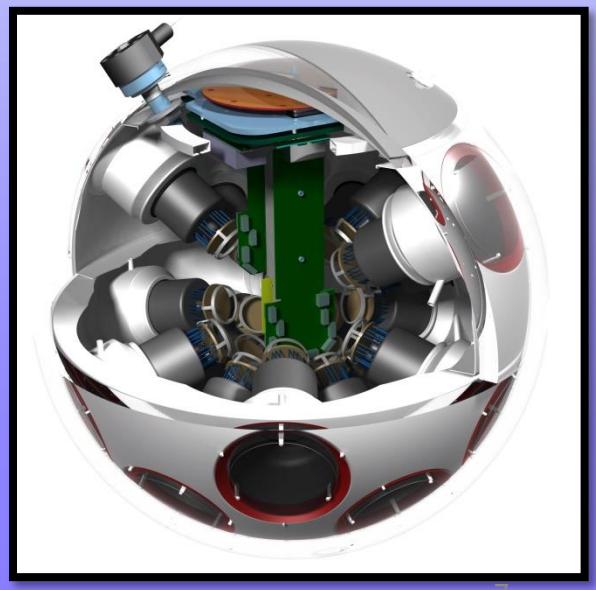
$E_{resol} = 25\%$ $\theta_{resol} = (m_p/E)^{1/2}$

The ORCA Detector

- **~5.7 Mt** instrumented
- **115** strings **(~50 kt ~ 2 × SK)**
- **18** DOMs / str **(~3 kt ~ MINOS)**
- **31** PMTs / DOM
- Total: **64k PMTs**

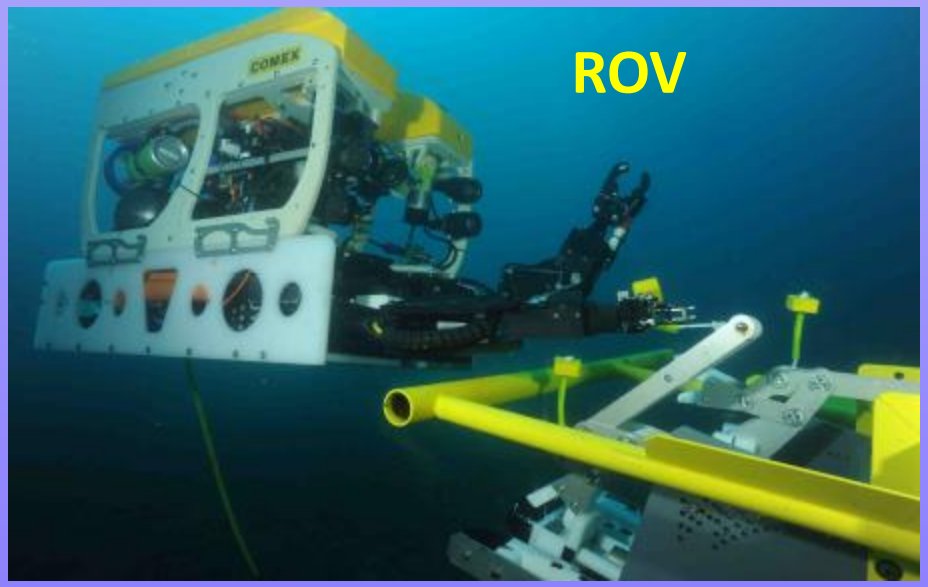


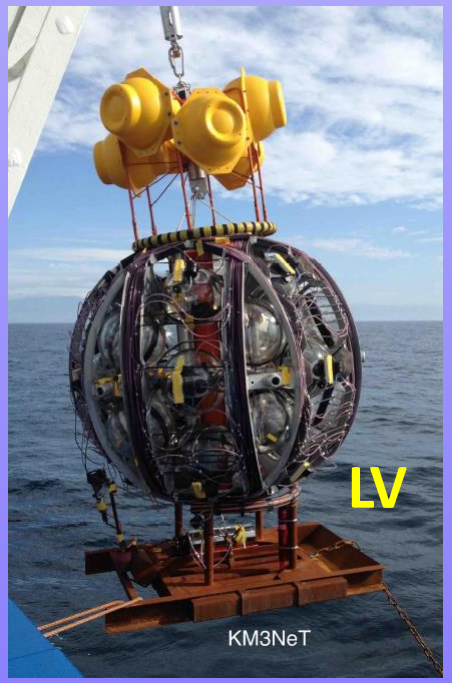




Deployment

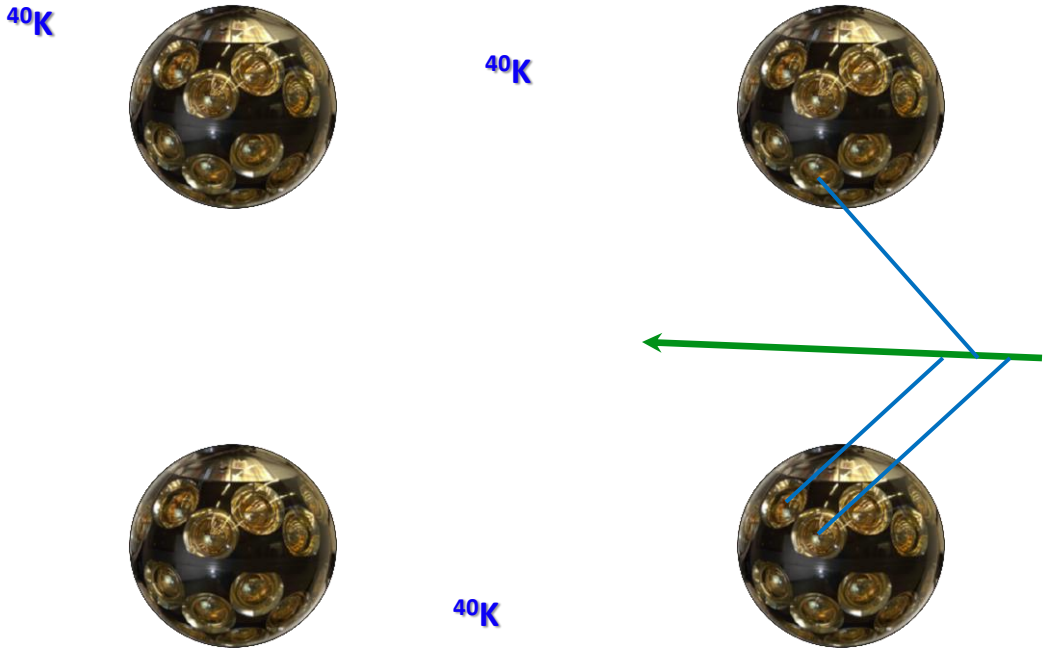
- String fitted to Launcher Vehicle
- Delivered at a **depth of 2450m**
- Dynamic Positioning: **1m precision**
- ROV connects cable to junction box
- Boat triggers unfurling of the string
- Watch ARCA string deployment at:
  https://www.youtube.com/watch?v=tR8jwgG6uzk





Trigger

- Optical background mostly from ^{40}K decays in the water
- Measured: **8 kHz** uncorr., **340 Hz** level-two coinc. / PMT **[Eur. Phys. J. C 74, 3056 (2014)]**
- Look for coincidences in time and PMT direction to reduce trigger rate.
- Causality further restricts space and time correlations for extra power.



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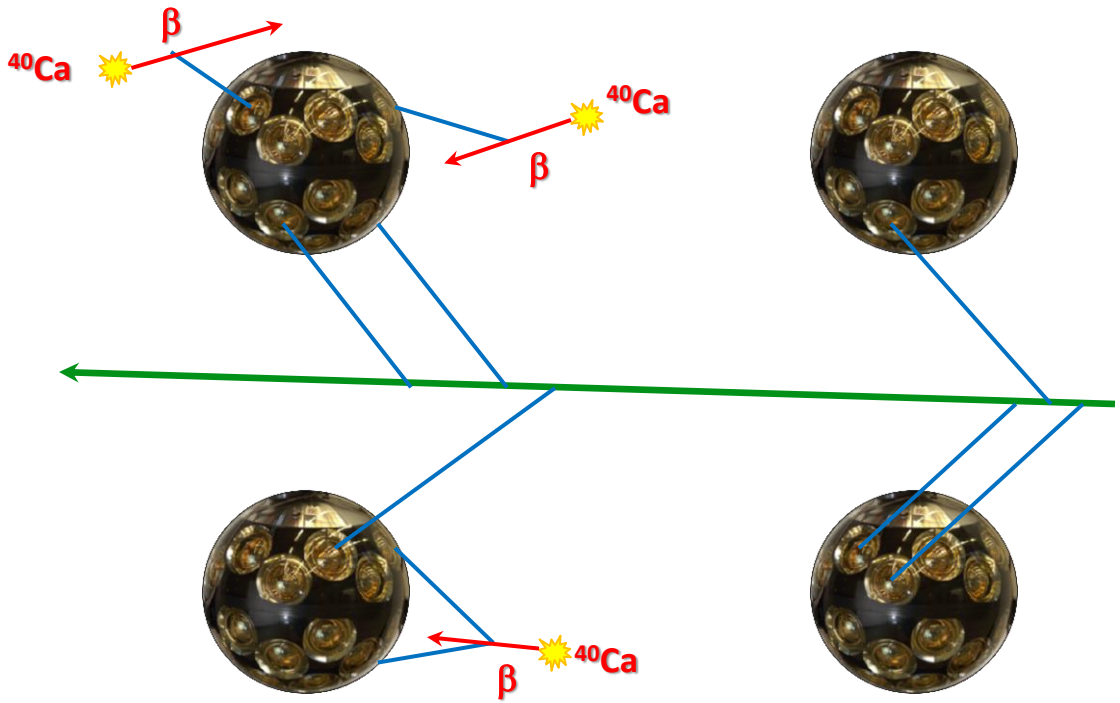

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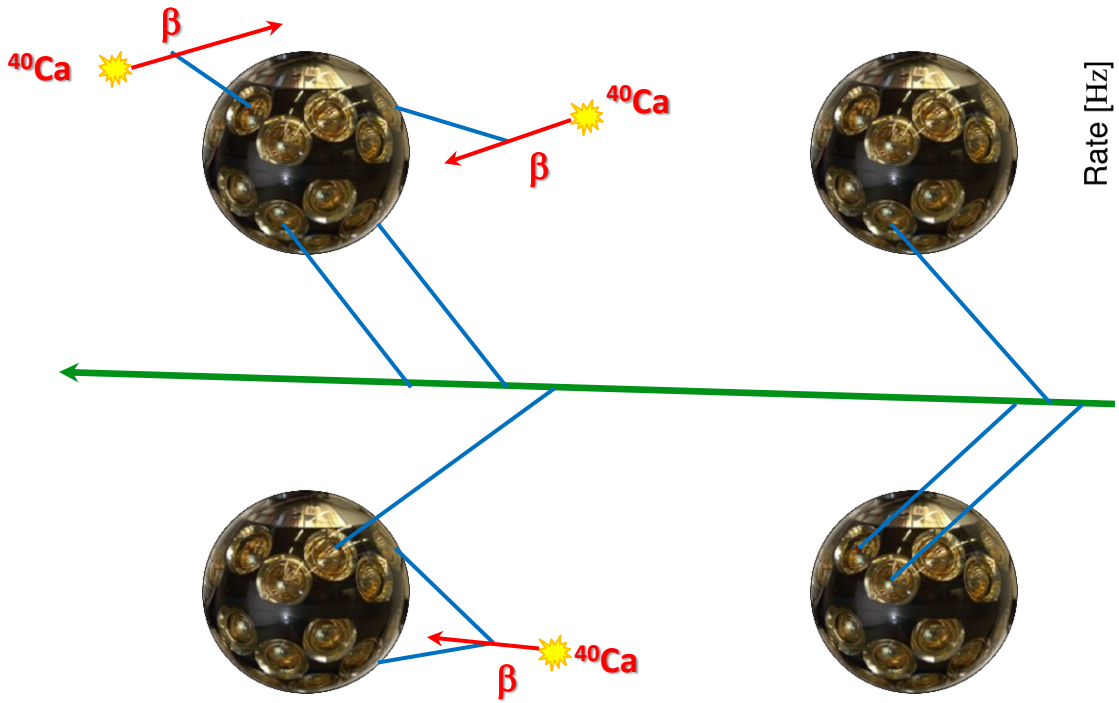
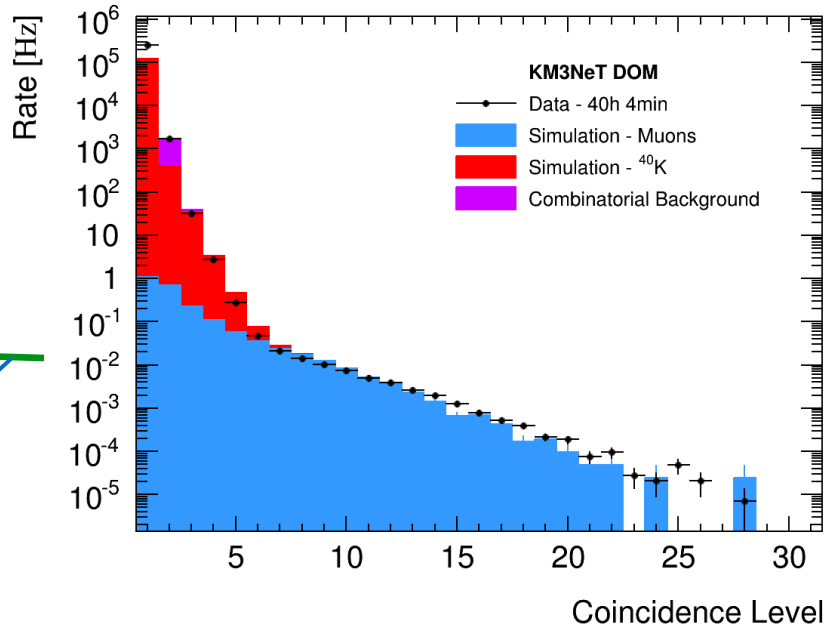
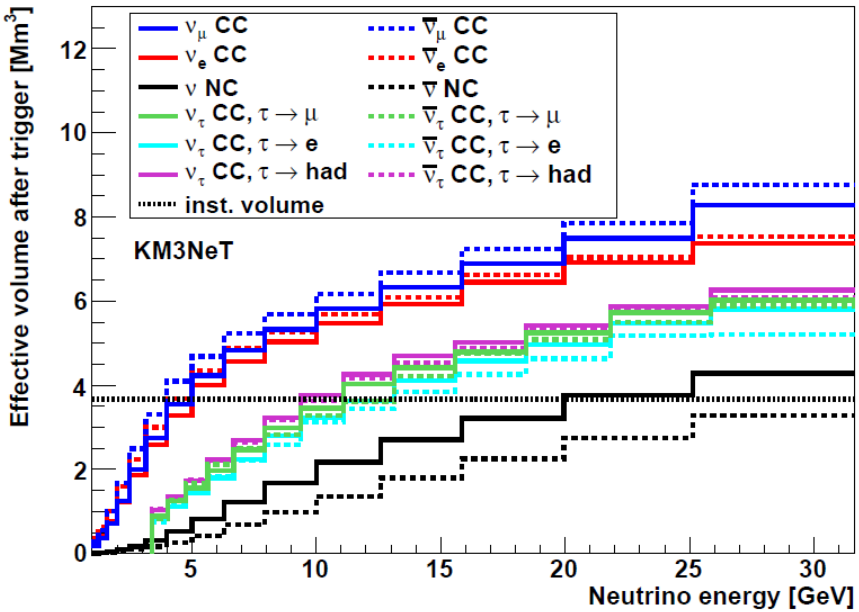
- Look for coincidences in time and PMT direction to reduce trigger rate.
- Causality further restricts space and time correlations for extra power.
- Multiple coincidences keep rate below a threshold (~50 Hz)

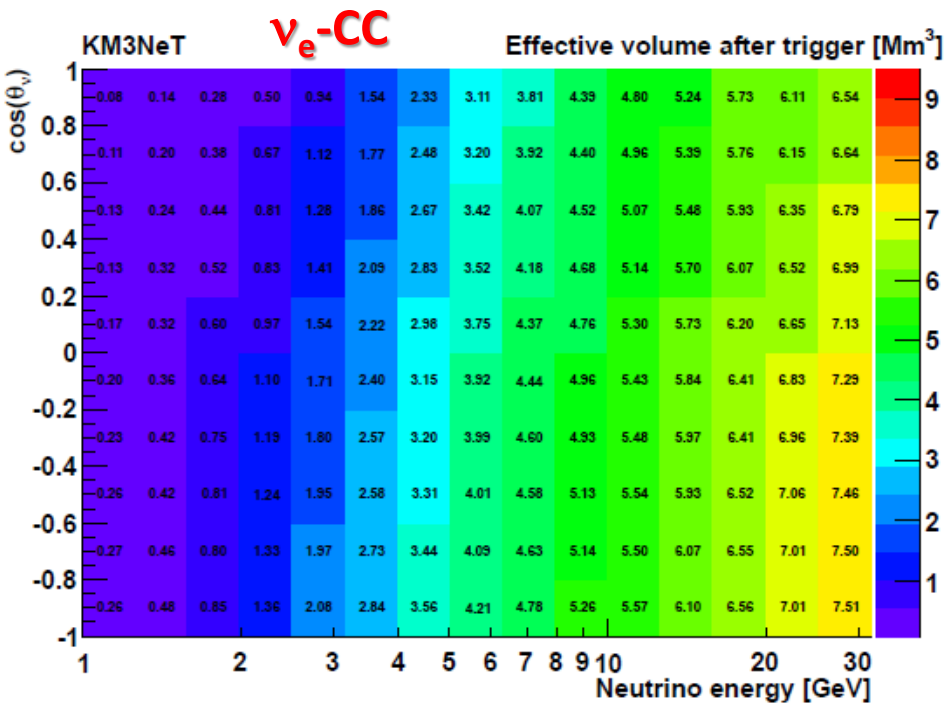




Trigger Performance

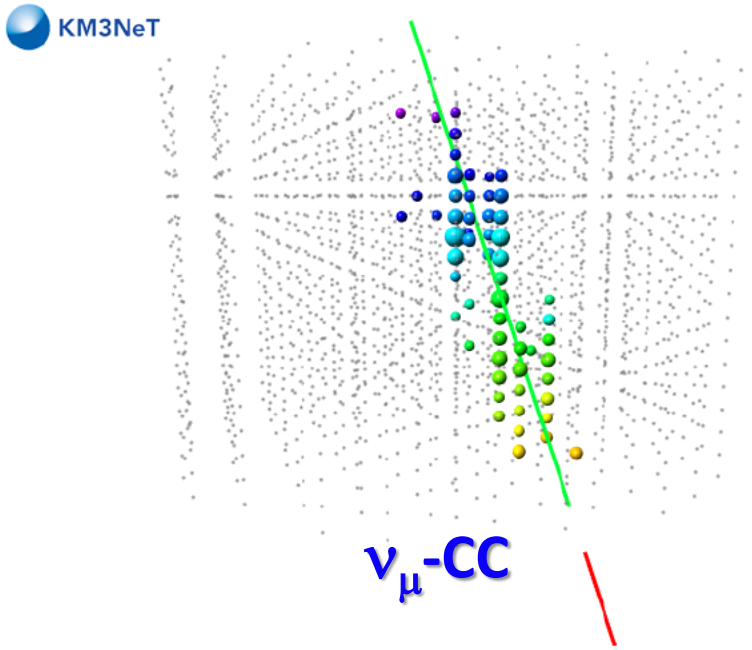
- Input a **conservative** noise rate of **10 kHz** uncorr. (**500Hz** level-two coinc.)
- Achieve a total triggered rate of **59 Hz**
- About **70%** of events contain a **muon** (41 Hz)
- High efficiency for ν_μ and ν_e above 4 GeV
- Slightly more efficient for up-going neutrinos (Larger PMT coverage)

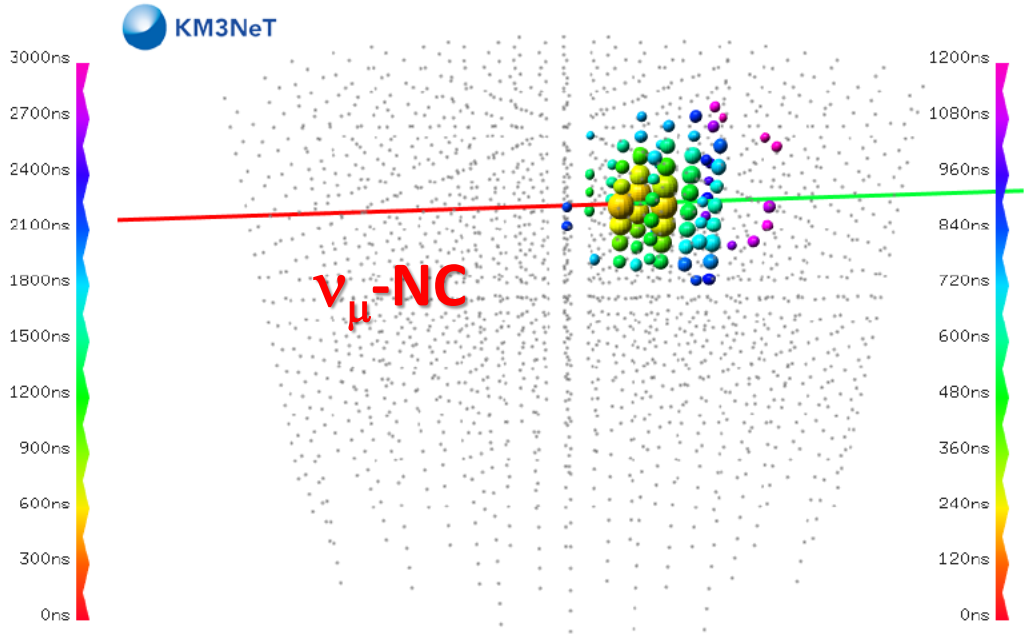




Measuring Neutrinos

- Neutrino interactions will generate **two main topologies** in ORCA
- Events containing **energetic muons** cross a large fraction of the detector, leaving a long trail of Cherenkov light. These are classified as **tracks**.
- Events with only **electromagnetic and/or hadronic cascades** generate most of their light in a short burst. These are classified as **showers**.

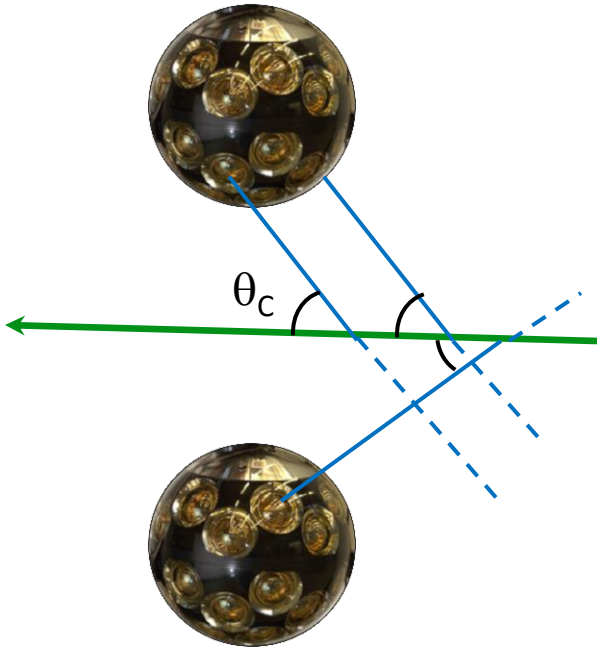




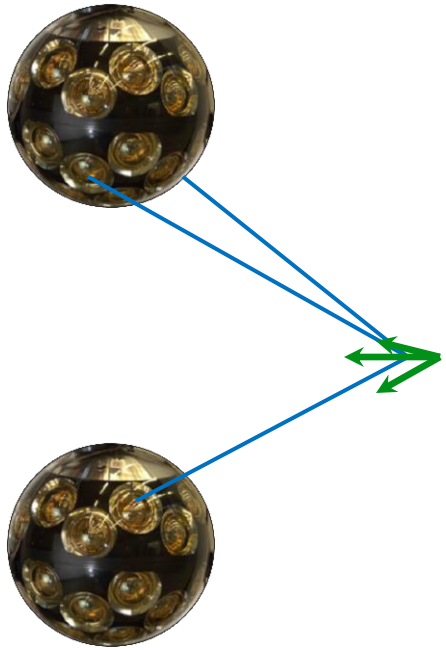
Reconstruction

1) Start with a track or shower hypothesis
2) Use **causality** to perform a robust **hit selection**
3) Find **vertex** and **direction** that best match hit pattern
4) Estimate track range for computing **track energy** (0.24 GeV / m)
5) Estimate **Shower energy** and direction from hit distribution after initial fit to the vertex position and time

Track Hypothesis



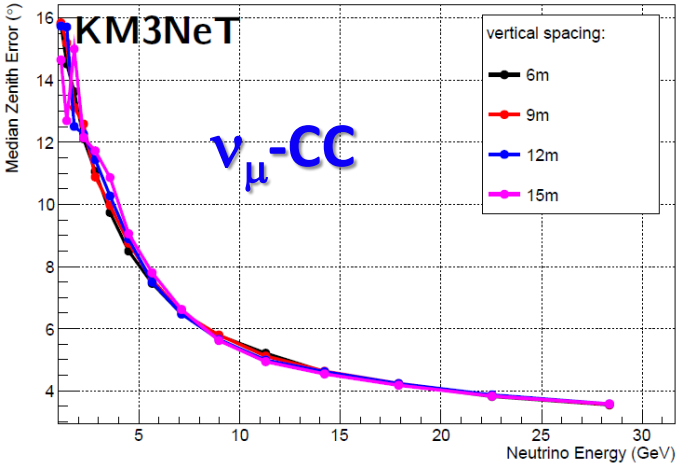
Shower Hypothesis



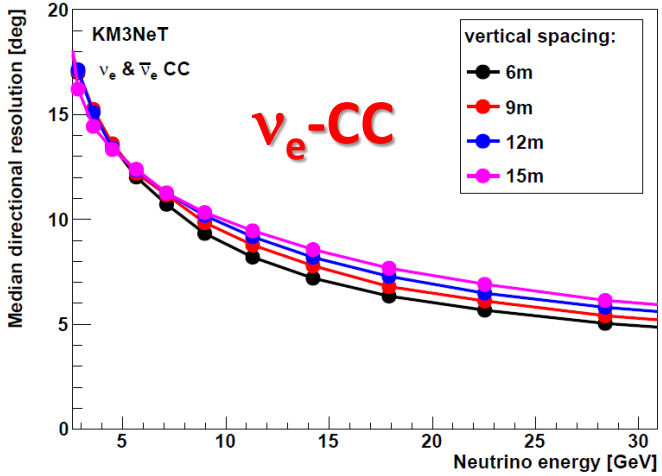
Reco Performance

- Better than 13˚ directional resolution above 5 GeV
- Energy res. sensitive to vertical spacing between DOMs at low energies

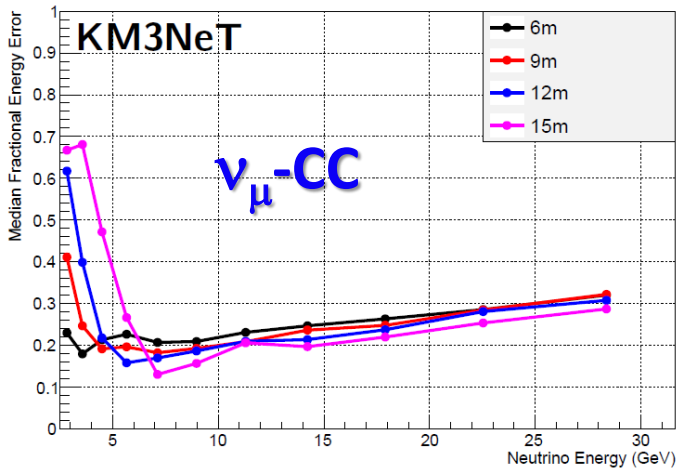
θ Res.



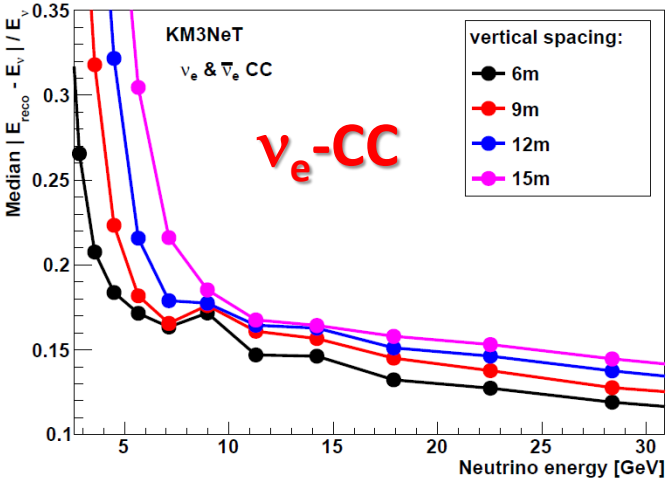
θ Res.



E Res.



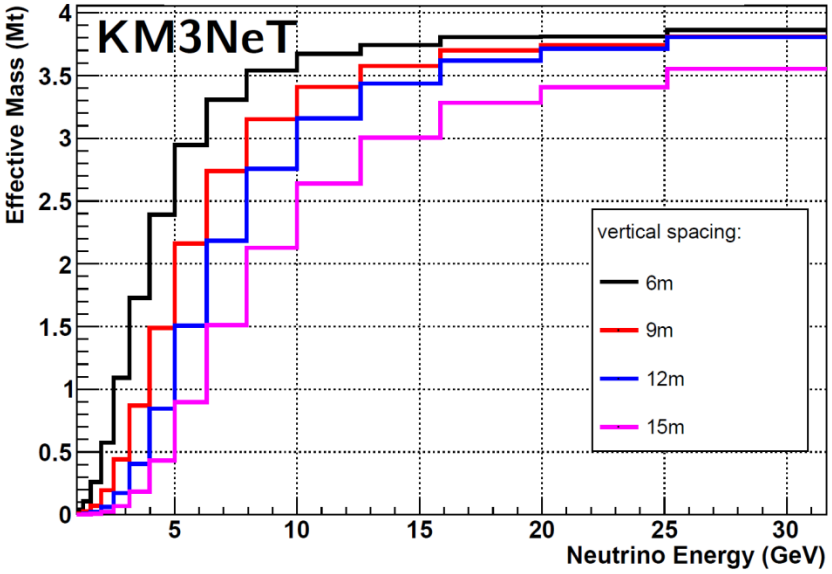
E Res.



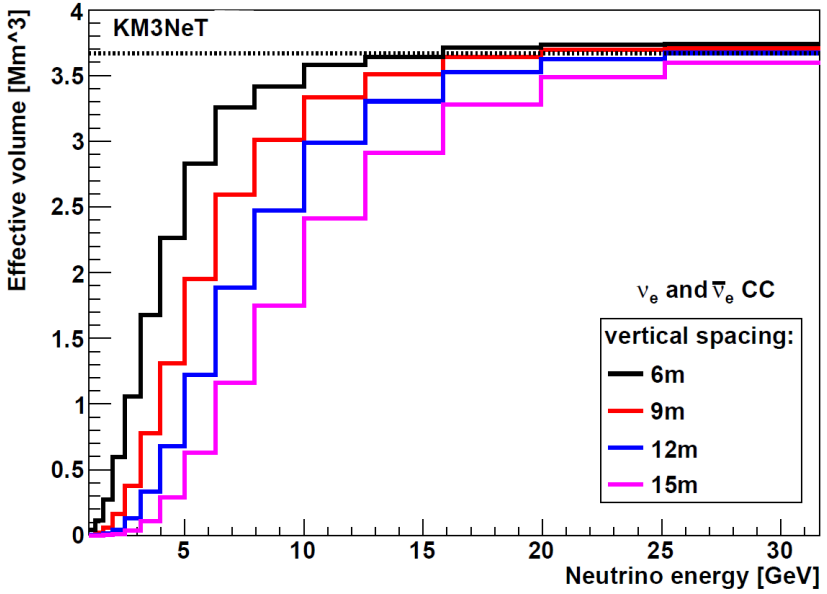
Optimizing DOM Spacing

- Simulated small (6m) vertical spacing detector
- Mask off 1/3, 1/2 or 2/3 of DOMs to emulate larger spacing
- **Smaller spacing** enables measurement at **lower energies**
- **Larger spacing improves statistics** due to larger volume
- **Tune spacing** to obtain maximum sensitivity to **Mass Hierarchy**

$\nu_\mu + \overline{\nu}_\mu$ CC



$\nu_e + \overline{\nu}_e$ CC



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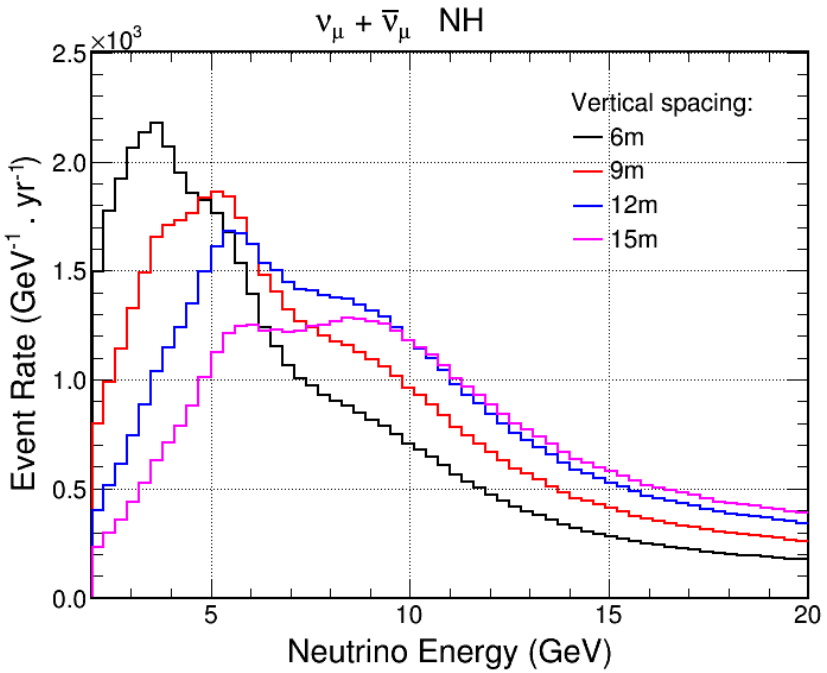
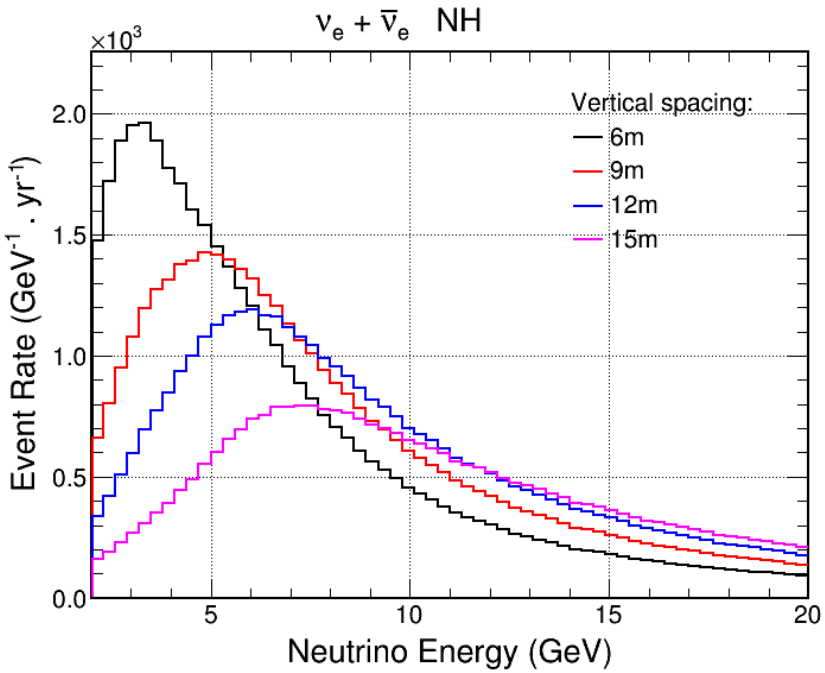
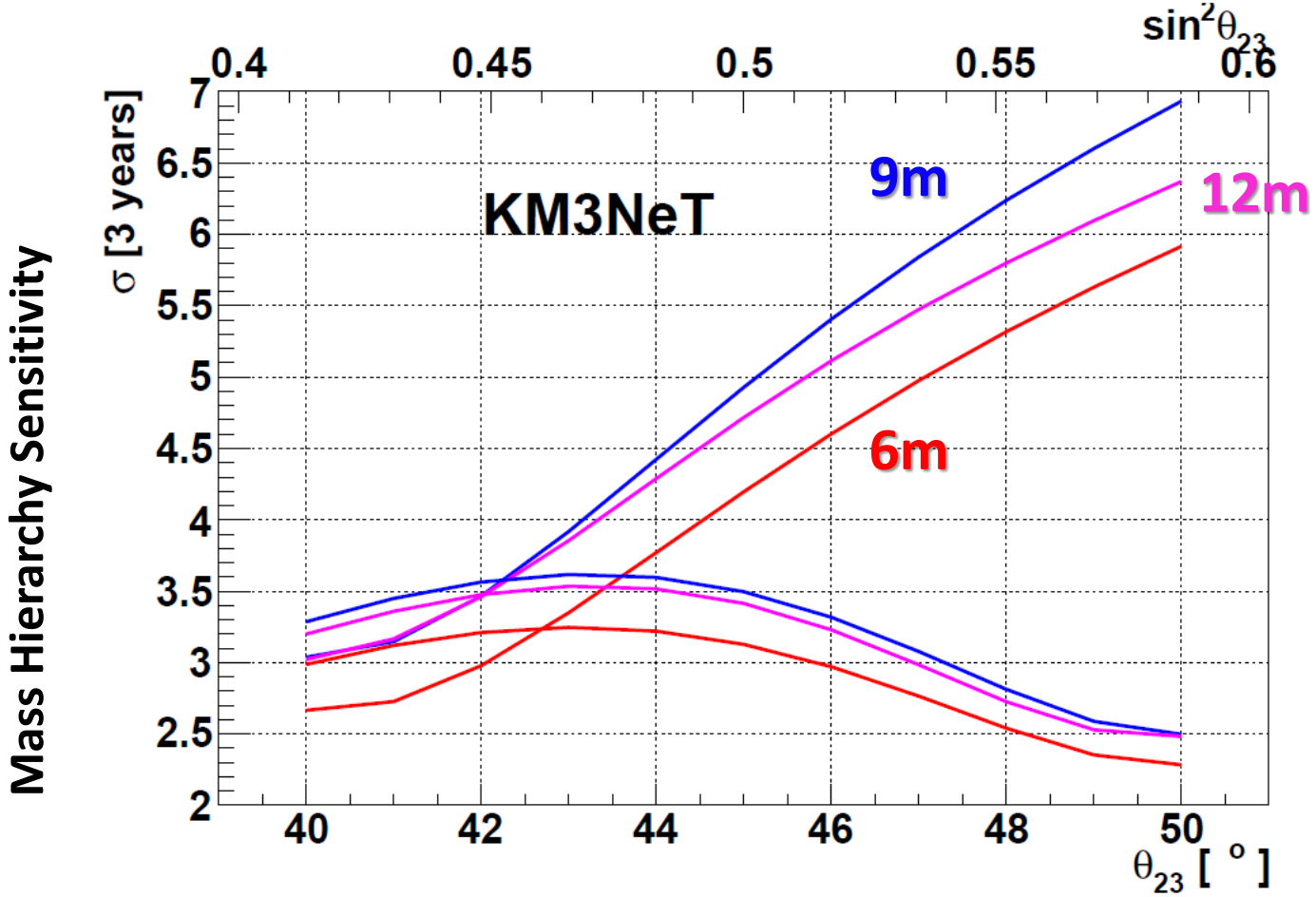




Derived from data in the KM3NeT 2.0 LoI: https://arxiv.org/abs/1601.07459

Simple χ^2 Analysis

- **9m spacing achieves best sensitivity**



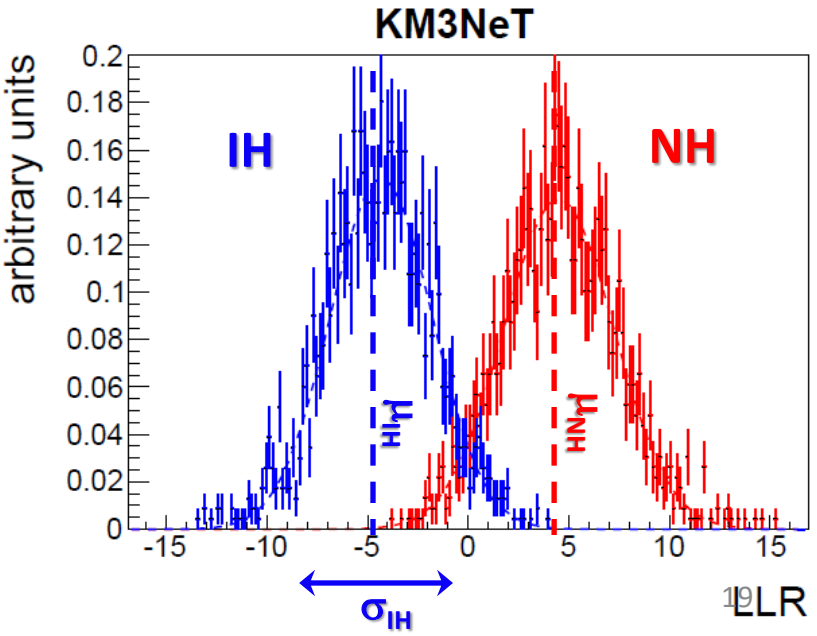
Full Statistical Analysis

parameter	*true value distr.*	*initial value 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	$\mu = 34$, $\sigma = 1$	nuisance	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	$\mu = 7.6$, $\sigma = 0.2$	nuisance	N/A
δ_{CP} [°]	0	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

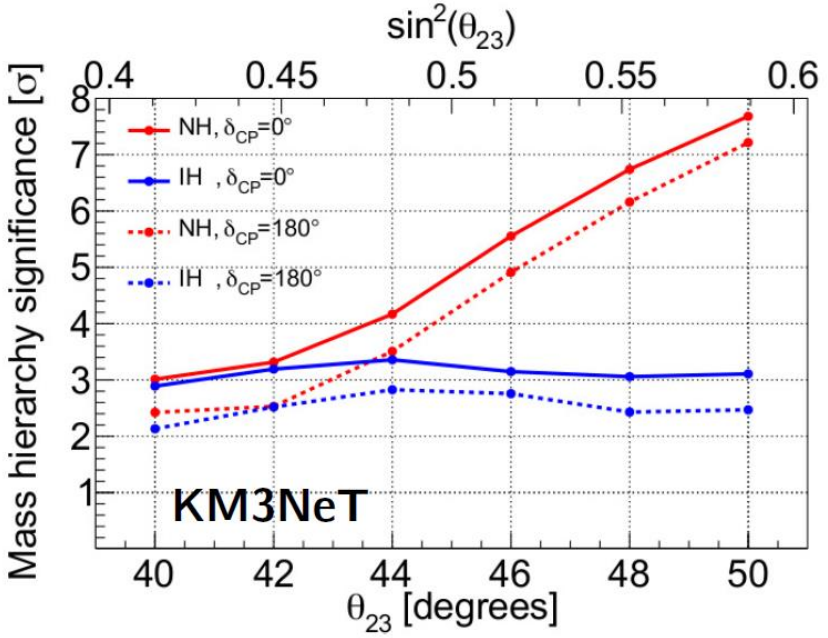
- Profile over 4 oscillation & 5 systematic parameters

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

- Generate pseudo-experiments and compute $\mathrm{LLR} := \log(\mathcal{L}_{NH}/\mathcal{L}_{IH})$
- For each MH assumption, LLR distribution will peak at different values
- **Median sensitivity**: probability of observing median LLR of wrong hierarchy for PEs generated with fixed true hierarchy

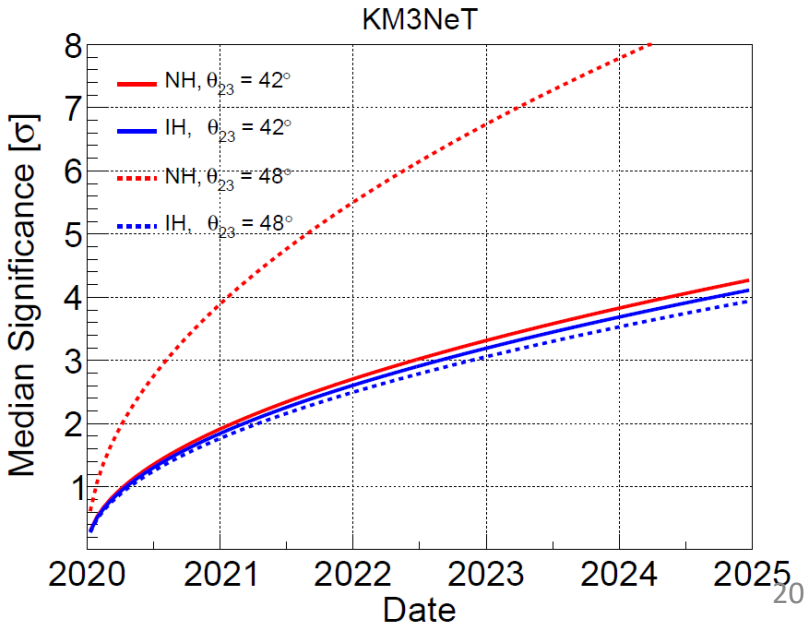


Sensitivity Results



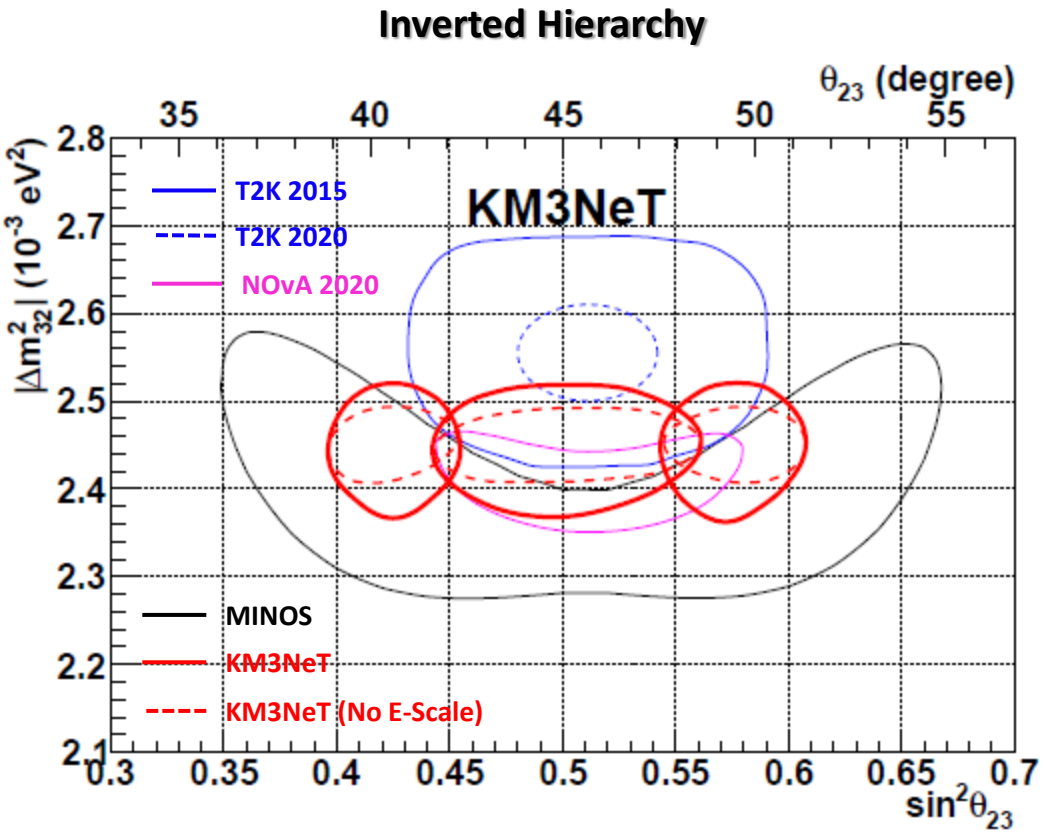
- **~3σ** MH sensitivity **in 3 years**
- The combination of **NH and upper octant** of θ_{23} would significantly improve sensitivity (**5σ in 3 years**)
- The value of δ_{cp} has small but non-negligible impact on sensitivity

- In the IH, sensitivity is mostly independent of octant of θ_{23}
- **Best case** scenario could achieve **>5σ by mid 2021** (1.5 years)



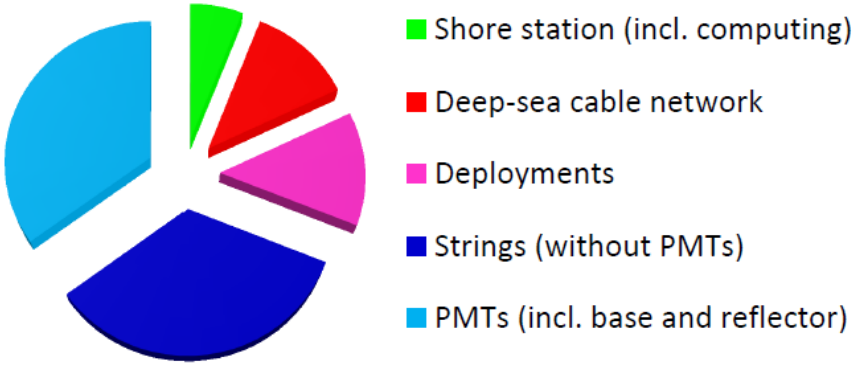
Other Parameters

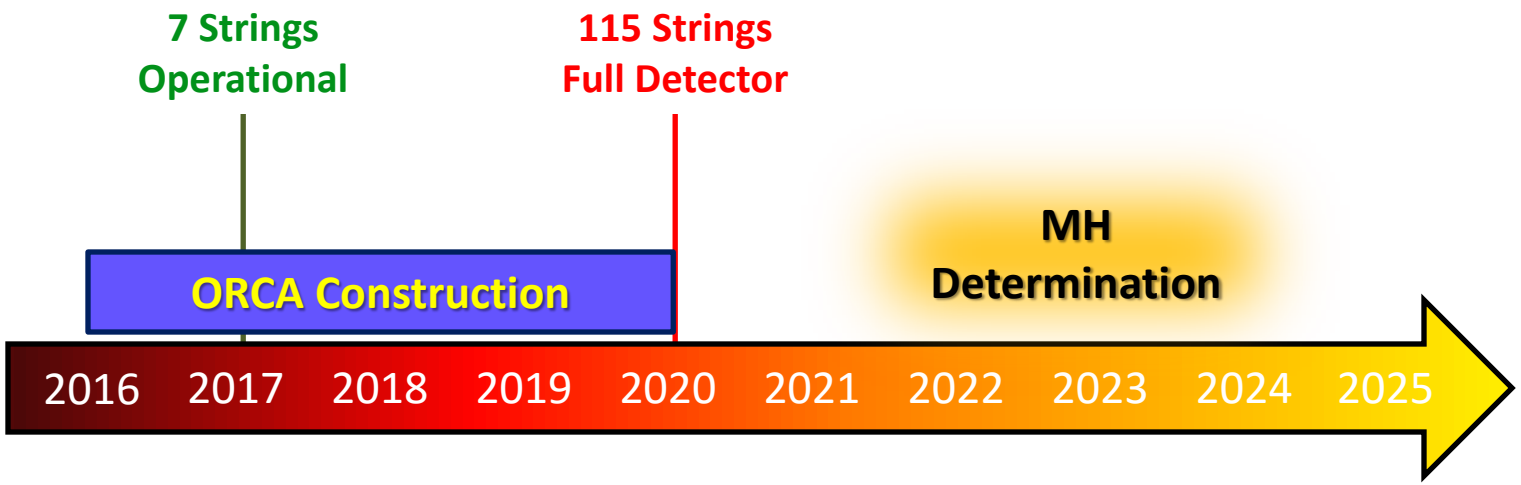
- High statistics and excellent resolution → Measure Δm^2_{32} and $\sin^2\theta_{23}$
- **Competitive with NOvA and T2K** projected sensitivity in 2020
- Achieve **2-3%** prec. in Δm^2_{32} and **4-10%** in $\sin^2\theta_{23}$
- Also sensitive to:
  - Oscillation into tau neutrinos
  - Earth chemical profile
  - Non-Standard Interactions
  - Sterile Neutrinos
  - And more…



Funding and Schedule

- Construction is ongoing
- 2 strings in operation (ARCA)
- **7 strings funded** for ORCA
- **Total ORCA cost: 40 M€**





Summary

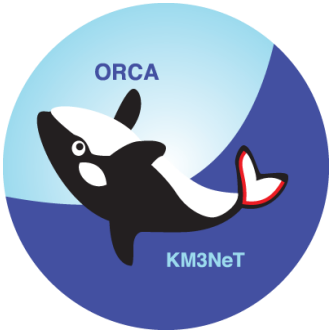
- ORCA is being built in the Mediterranean sea to measure oscillations with atmospheric neutrinos

- Main goal is to determine the **Neutrino Mass Hierarchy**

- ORCA will also improve measurements of other oscillation parameters such as Δm^2_{32} and θ_{23}

- Detector can be completed by 2020 and data can be taken during construction time

- If funded, NMH could be **determined by 2023**



★ Read our LoI at: https://arxiv.org/abs/1601.07459
(Accepted for publication in J. Phys. G)

Thank you!