

# KM3NeT/ORCA and the neutrino mass ordering

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Nikhef neutrino forum meeting  
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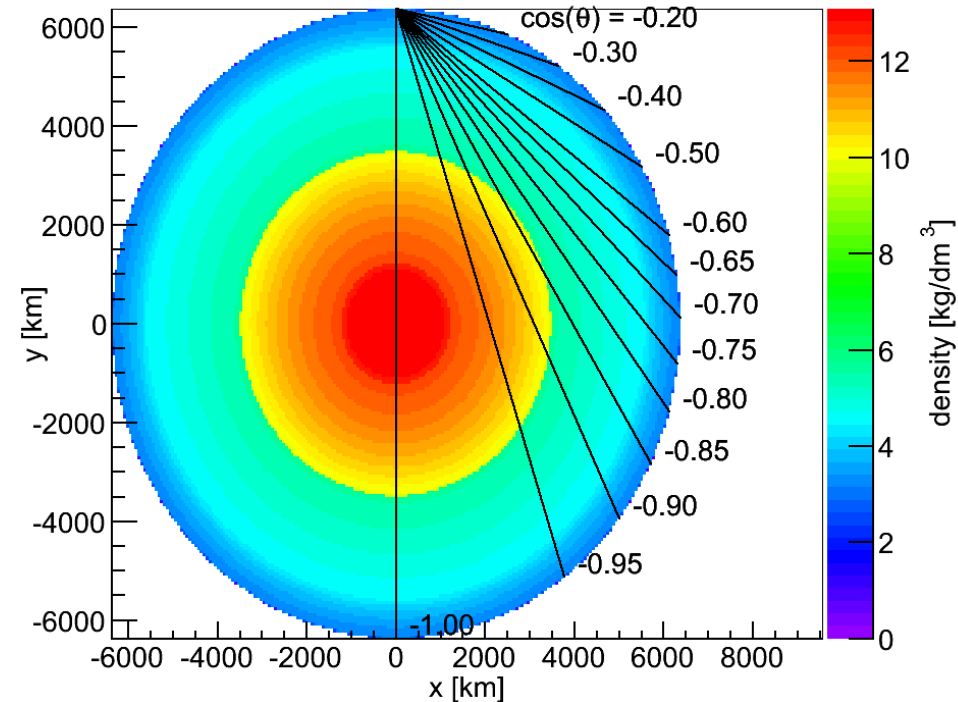


**KM3NeT**

*Opens a new window on our universe*

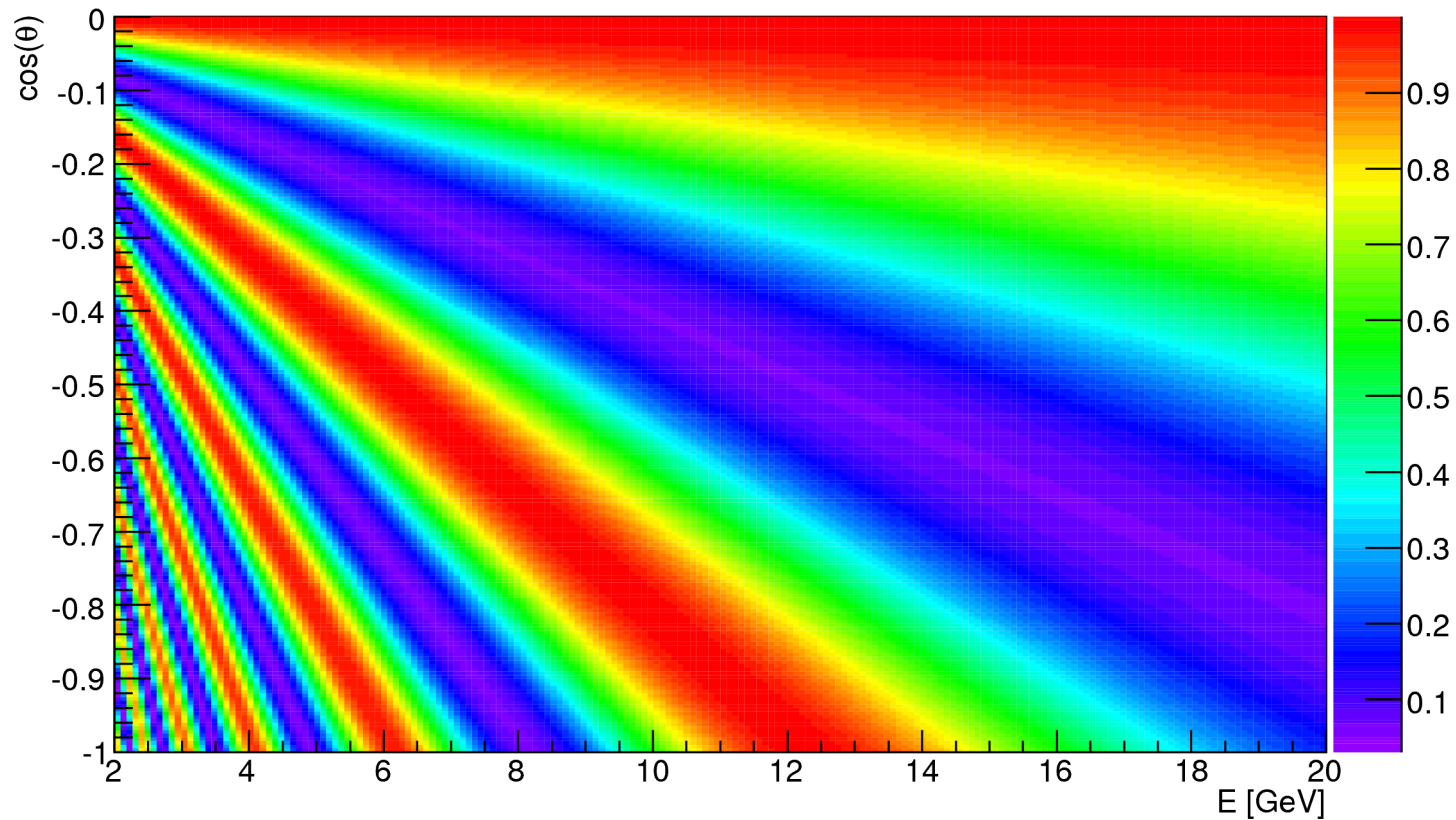
# KM3NeT/ORCA – basic principle

- Atmospheric neutrinos
- Traverse Earth
- MSW effect
  - modifies neutrino oscillations
  - characteristic signature as a function of energy and zenith angle
  - allows measurement of oscillation parameters (mass ordering)



# KM3NeT/ORCA – basic principle

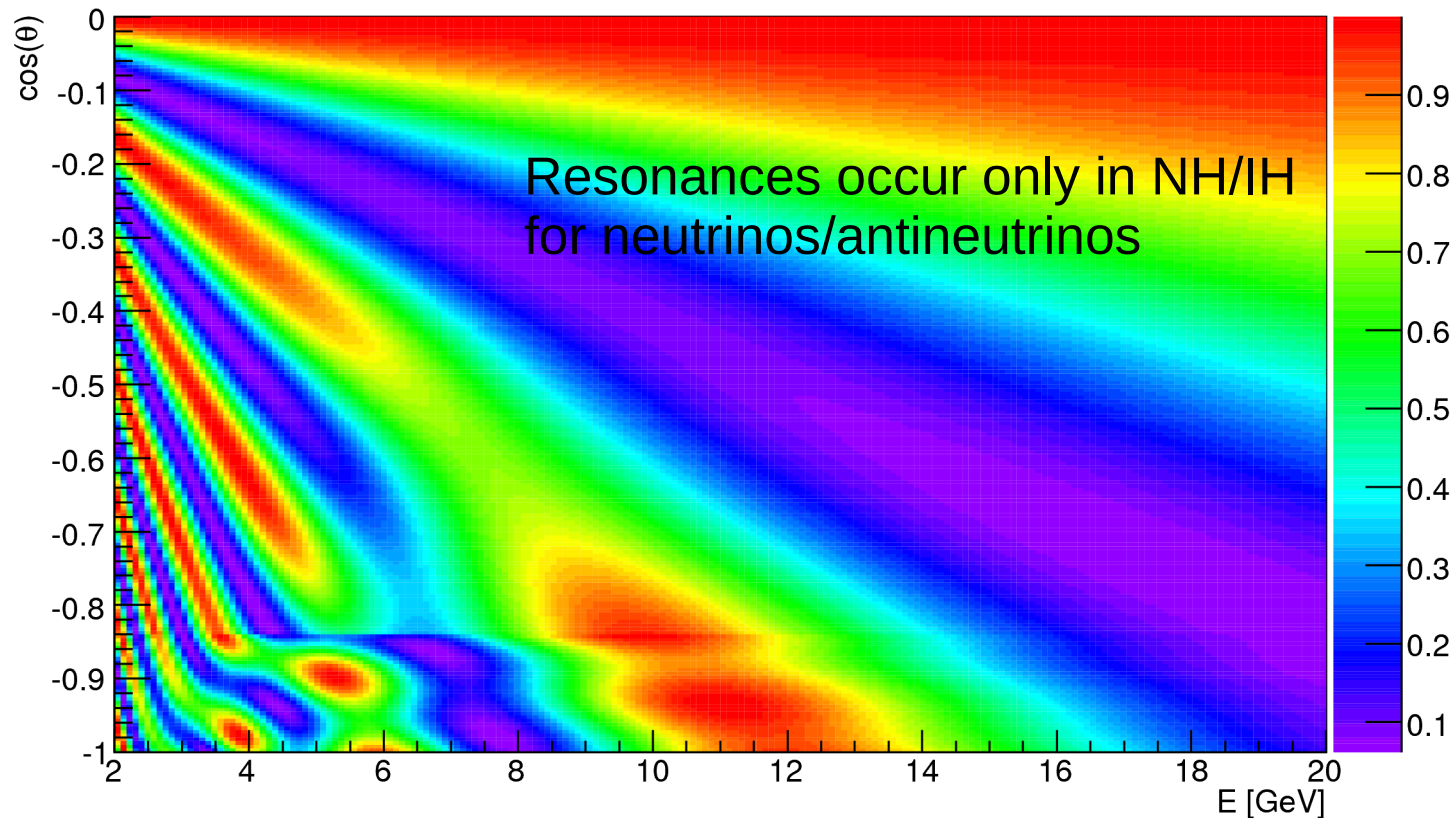
Oscillation probability for muonneutrino to muonneutrino



*Without MSW effect*

# KM3NeT/ORCA – basic principle

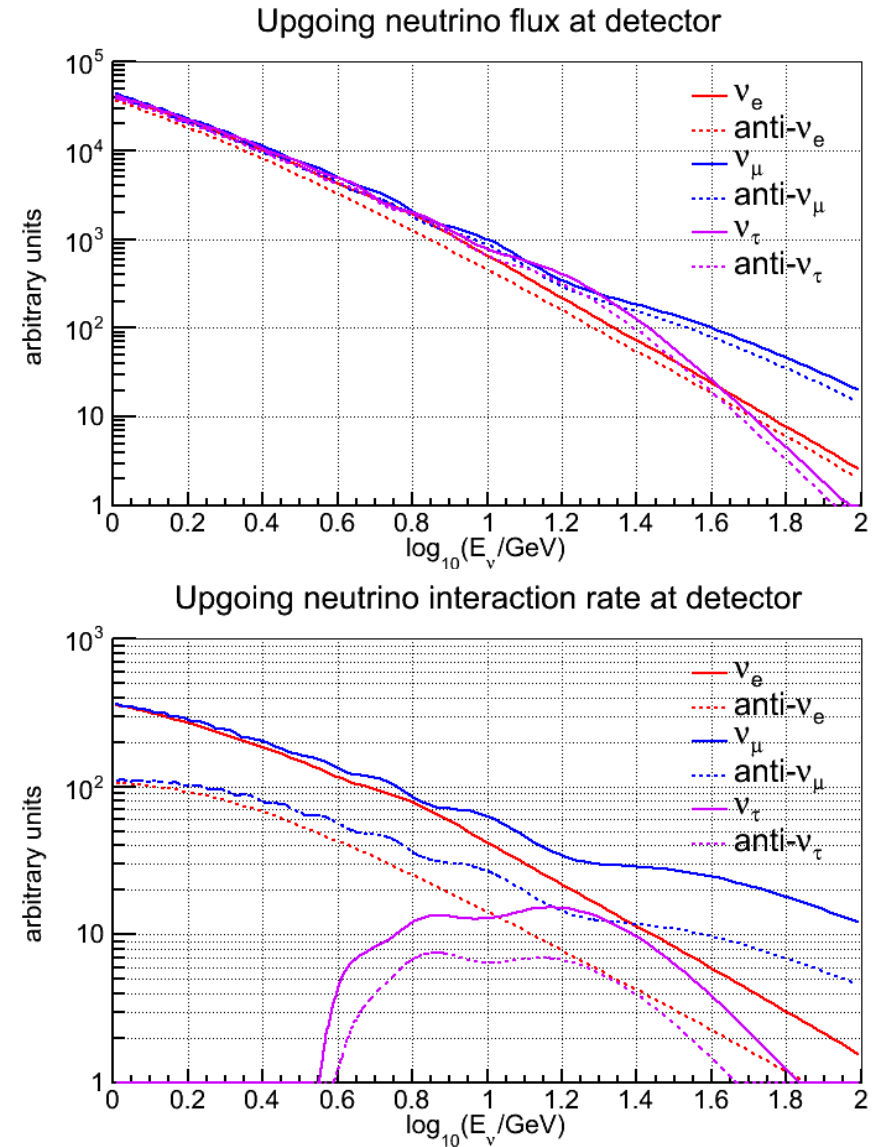
Oscillation probability for muonneutrino to muonneutrino



*With MSW effect*

# Atmospheric neutrinos

- Neutrino/antineutrino asymmetry
  - small in flux
  - large in interacting events (due to cross-section)



# Neutrino interactions

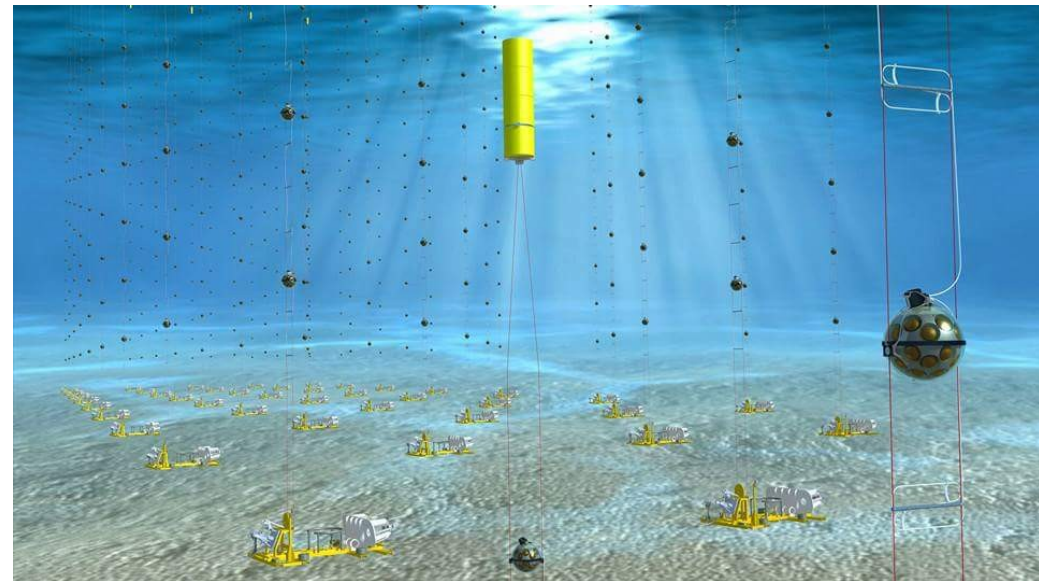
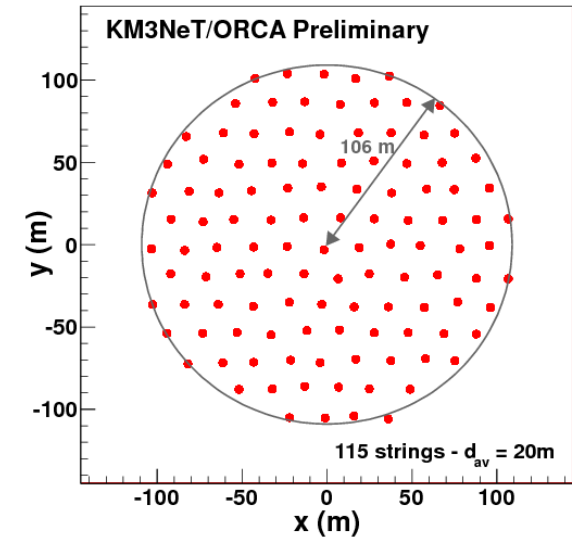
- NC interactions
  - background
- CC interactions
- Two signal classes
  - **Track** = mostly CC muon (anti)neutrino
  - **Cascade** = everything else
- **Very high statistics**

type	events/year
$\nu_e$	11.3k
$\nu_\mu$	16.1k
$\nu_\tau$	2.1k
anti- $\nu_e$	4.6k
anti- $\nu_\mu$	7.4k
anti- $\nu_\tau$	0.9k

*Expected number of detected upgoing CC interactions per year*

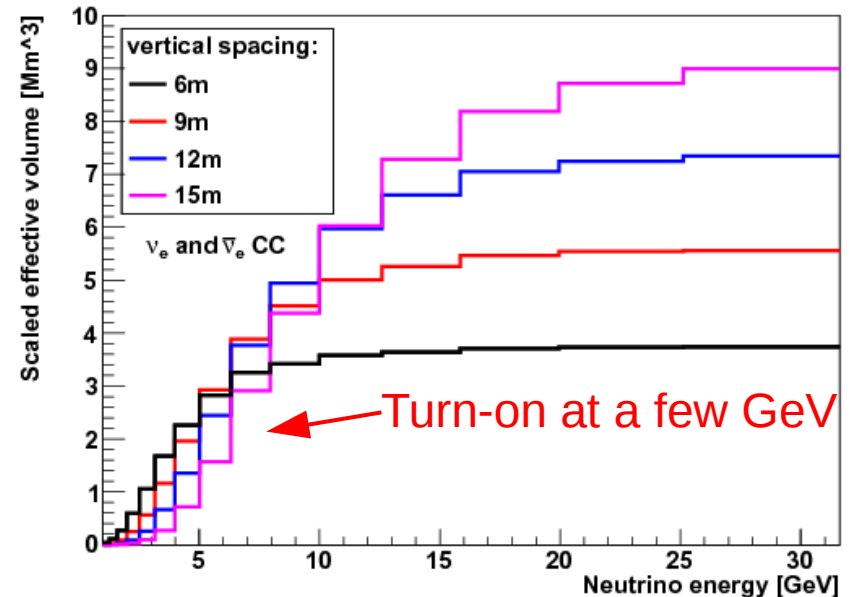
# Detector

- Underwater PMT array
  - 115 strings
  - 18 KM3NeT DOMs per string
  - 31 PMTs per DOM
- Dimensions
  - 9m vertical spacing (optimized)
  - 20m average inter-string distance
  - approx. 5.5 Mton instrumented volume



# Reconstruction

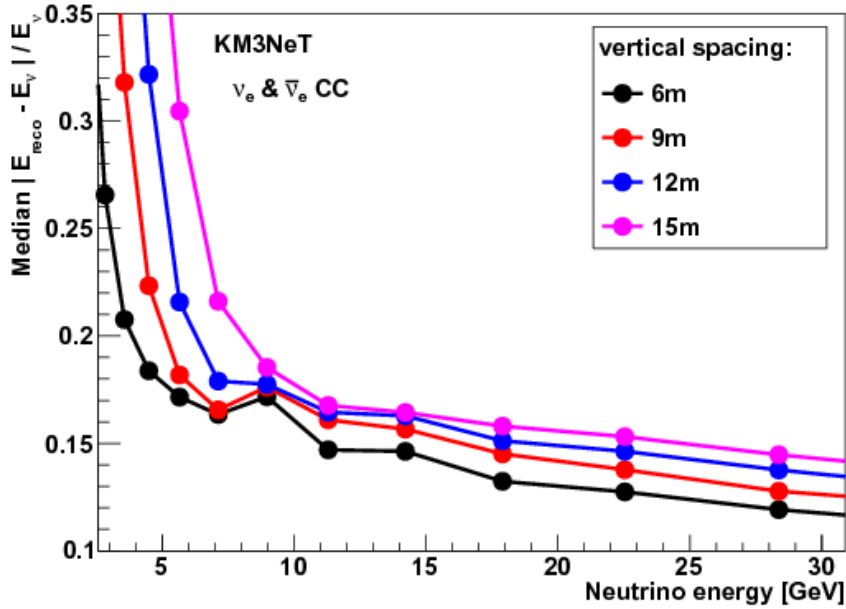
- Different from dense water cherenkov / LAr TPC
  - no particle-by-particle reconstruction or individual cherenkov rings
  - mostly shower and leading lepton
  - energy threshold at a few GeV
- Dedicated track and cascade algorithms



*Electron neutrino CC  
effective volume*

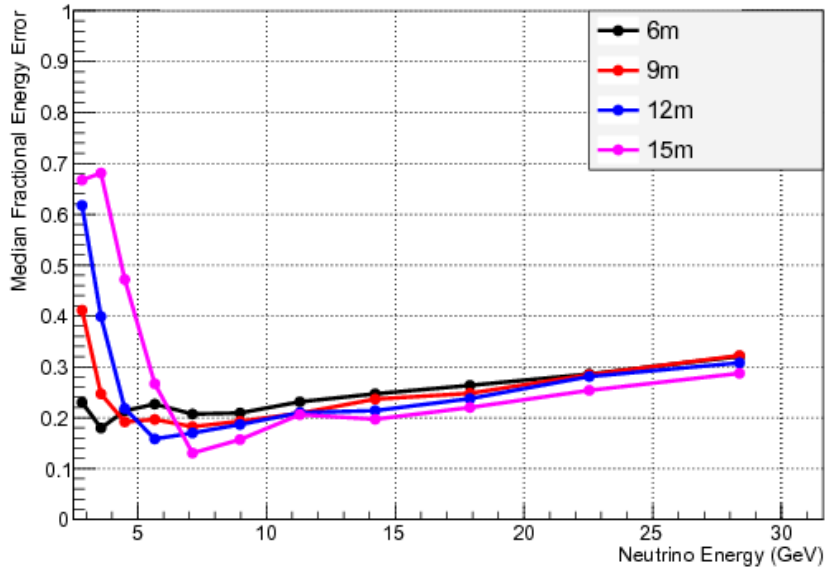
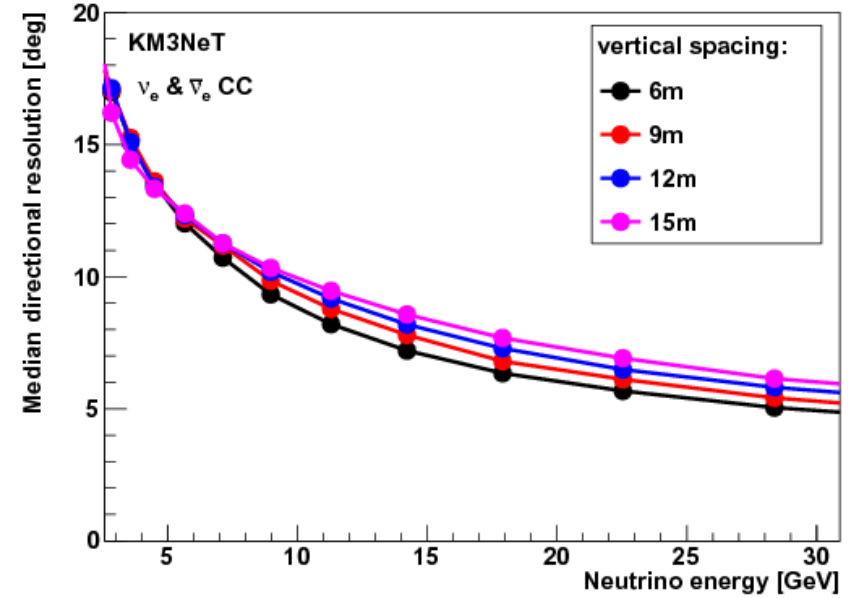


# Energy resolution (order of magnitude 15-20%)

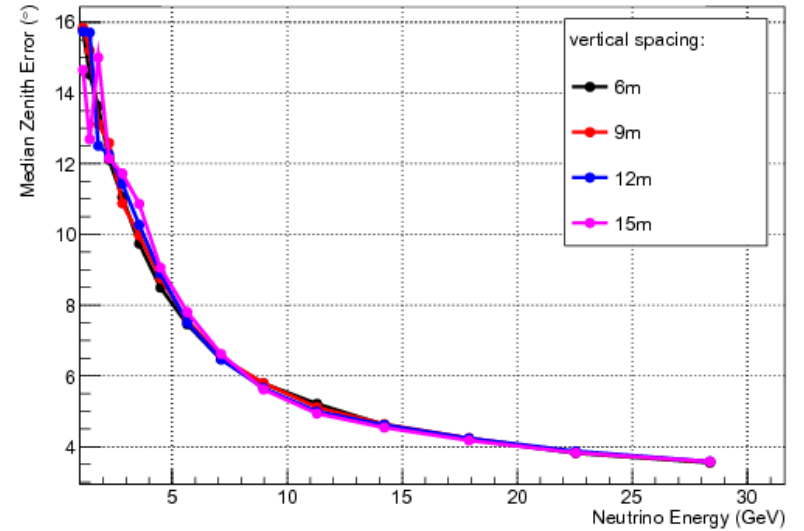


electron

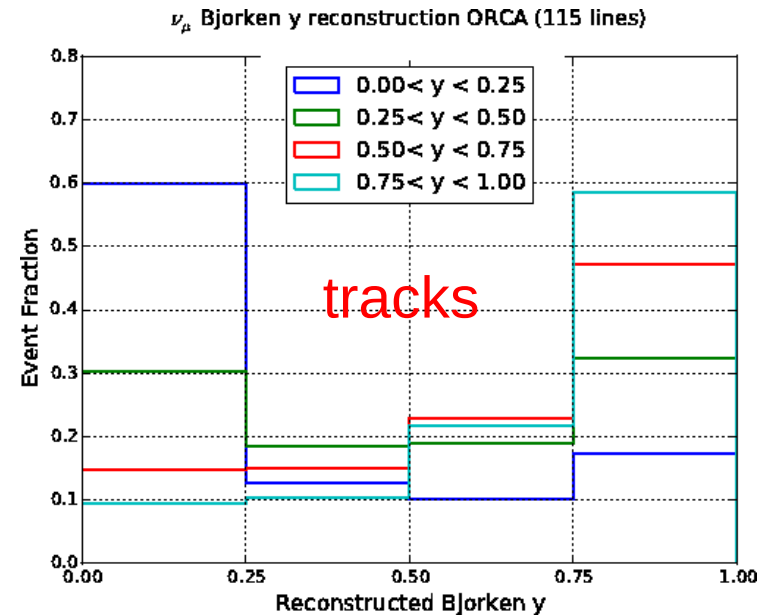
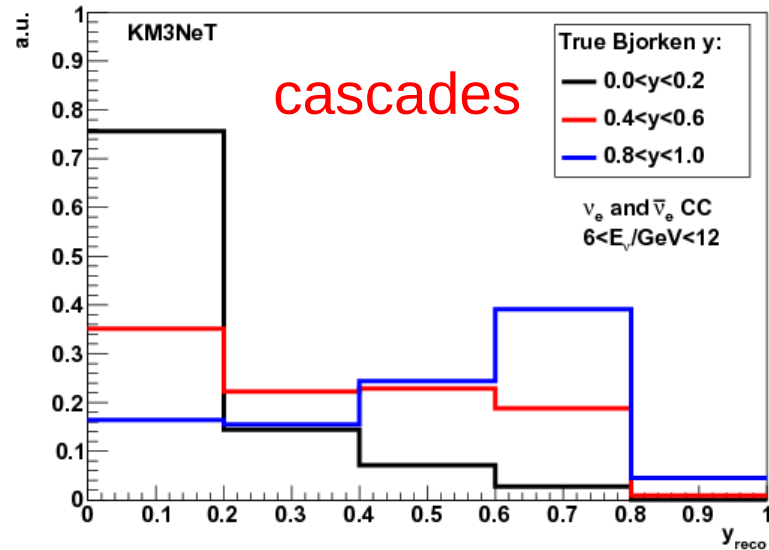
# Direction resolution (order of magnitude 10 degrees)



muon



# Bjorken $y$

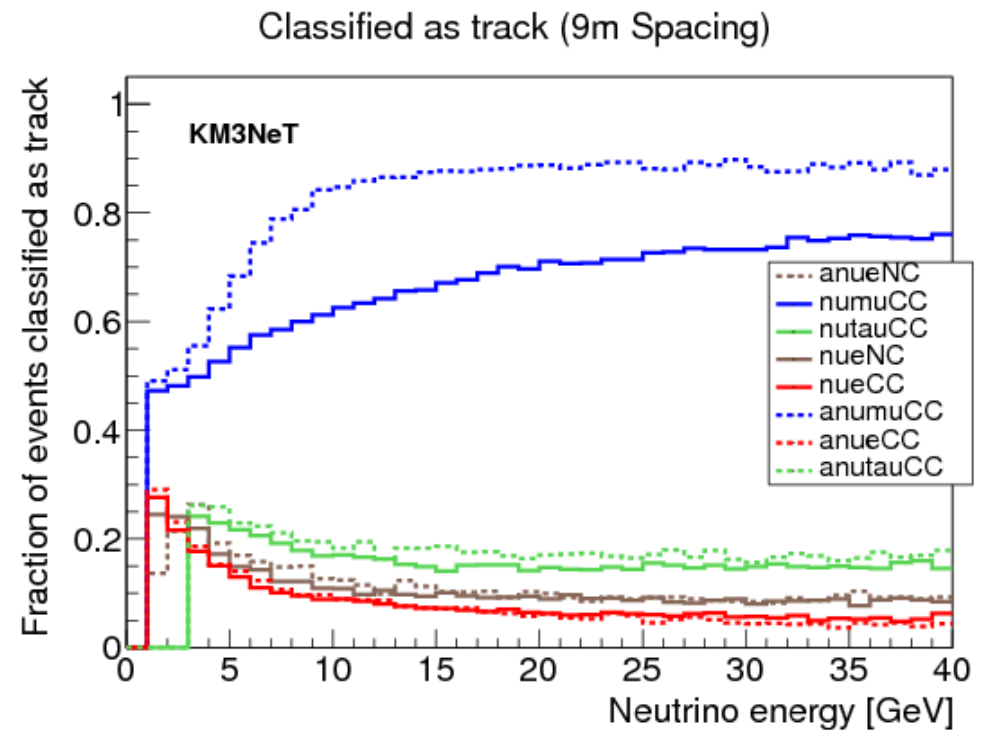


*Reconstructed inelasticity for CC neutrino events in for different true bjorken  $y$  ranges.*

- distribution is different for neutrinos and antineutrinos
- some statistical separation is possible
- performance improvement to be investigated

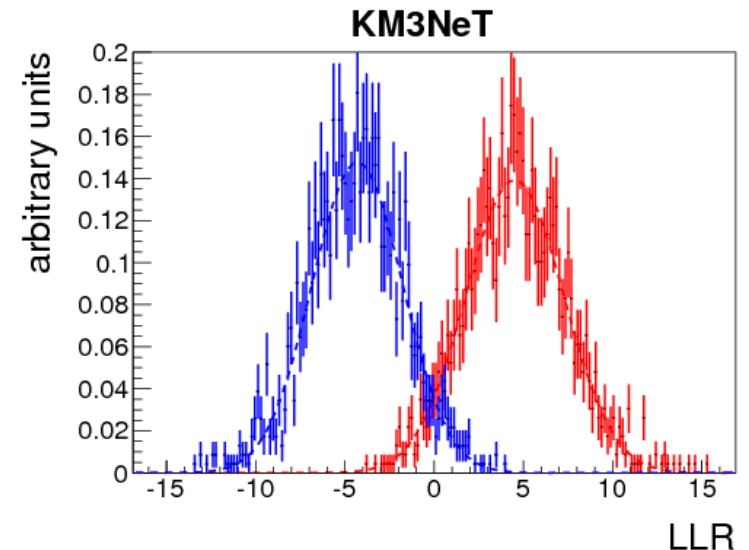
# Particle identification

- Rejection of atmospheric muons
  - basic cuts: zenith, track quality, reconstructed vertex position
- Track/shower classification
  - boosted decision trees
  - using reconstruction input
- Update in the pipeline
- Purity vs efficiency balance still to be optimized

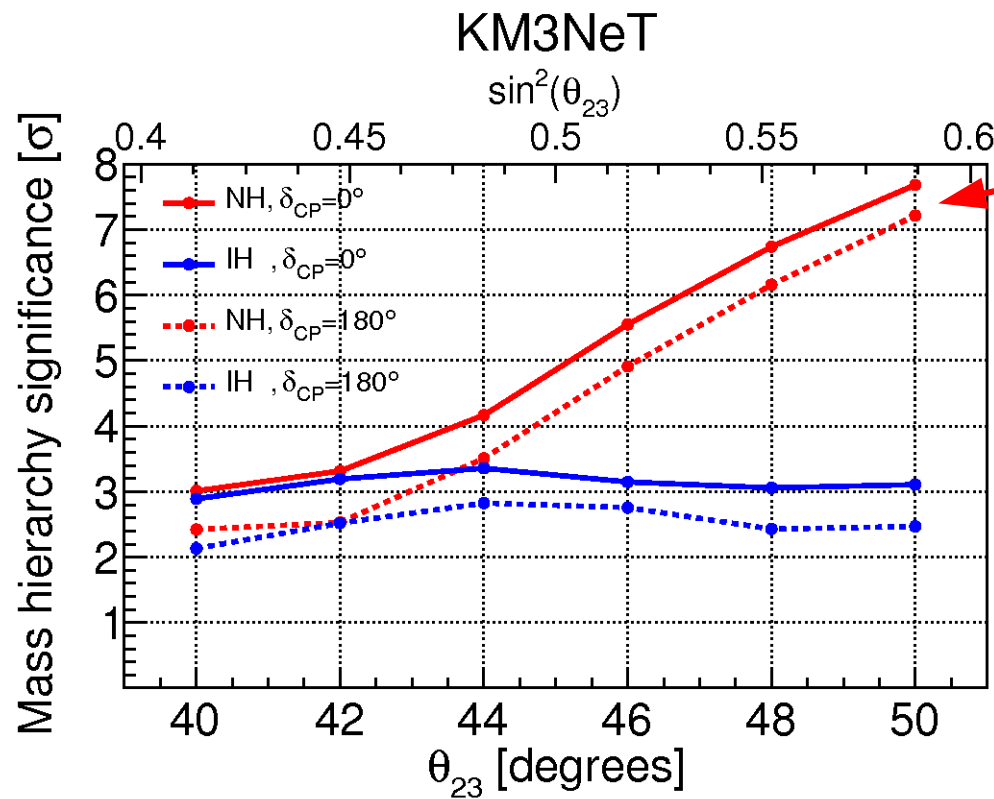


# Mass ordering sensitivity calculation

- Pseudo-experiments
  - minimize likelihood w.r.t. oscillation parameters and systematics
  - for NO and IO
- Using log likelihood ratio (LLR) discriminator
  - log ratio of best-fit likelihood for NO and IO
- Median sensitivity



# Hierarchy measurement

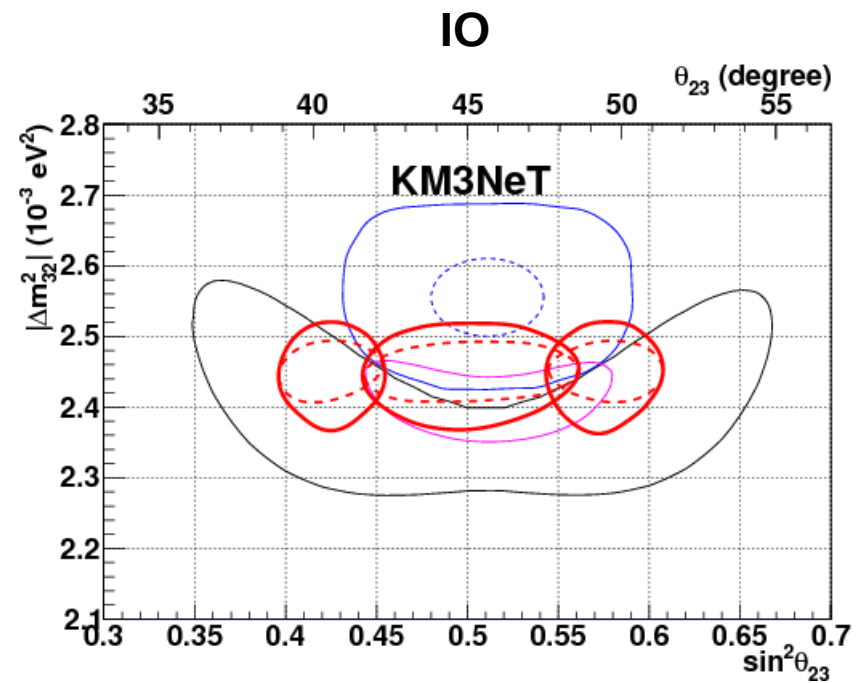
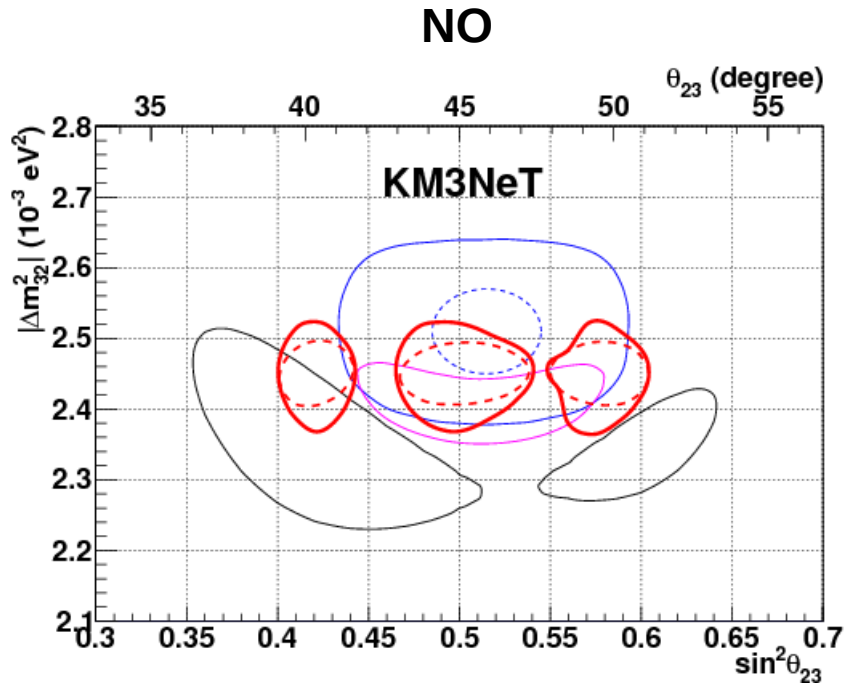


Note high sensitivity for combination NO, second octant  $\theta_{23}$

True value of  $\delta_{CP}$  has small impact

*Median sensitivity to the MH for three years of ORCA operation time, as a function of the true value of  $\theta_{23}$ .*

# Sensitivity to $\theta_{23}$ and $\Delta M^2$



$1\sigma$  contours on  $\theta_{23}$  and  $\Delta M^2$

**red solid:** 3 years of ORCA operation time for  $\Delta M^2 = 2.45 \times 10^{-3} \text{ eV}^2$  and three different true values of  $\sin^2\theta_{23}$ : 0.42, 0.50 and 0.58

**black solid:** MINOS current

**blue solid:** T2K current, **dashed** T2K predicted 2020

**magenta:** NOVA predicted 2020

# And then we have...

- Tau neutrino appearance
  - to probe unitarity of PMNS matrix
- Dark matter
  - neutrinos from gravitationally bound WIMPs in the Sun
- Non-standard interactions
  - non-EW interactions of neutrinos with matter leptons (u, d, e)

# Conclusions & outlook

- ORCA 3 year expectation
  - $3\sigma$  neutrino mass ordering measurement
  - competitive measurements of  $\theta_{23}$  and  $\Delta M^2$
- Work ongoing
  - reconstruction and particle ID
  - Bjorken  $y$  reco and impact on sensitivity
  - Improvement of sensitivity study





# Backup slides

# Systematics

- Atmospheric flux
- Interaction cross-section
- Implementation in Lol sensitivity study
  - overall scaling
  - NC scaling
  - ratio neutrino/antineutrino
  - ratio muon/electron flavour
  - energy slope

# Oscillation parameter overview

- $\theta_{23}$ 
  - part of measurement
  - large effect on sensitivity
  - partial octant degeneracy with hierarchy
- $\Delta m_{31}^2$ 
  - part of measurement
- $\Delta\text{CP}$ 
  - small effect on MHS
  - very little sensitivity to it
  - super-ORCA/PINGU?  
<https://arxiv.org/abs/1406.1407> (Razzaque, Smirnov)
- $\theta_{13}$ ,  $\theta_{12}$ ,  $\Delta m_{21}^2$ 
  - strong constraints by world data
  - ORCA sensitivity negligible