Introduction to KM3NeT/ORCA

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October 14, 2016

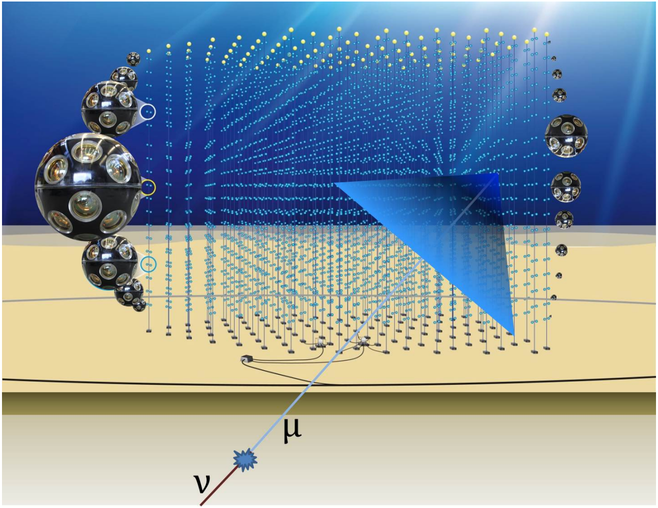


Figure 1: An artist's impression of the KM3NeT telescope array.

Detection Principle
Deployment

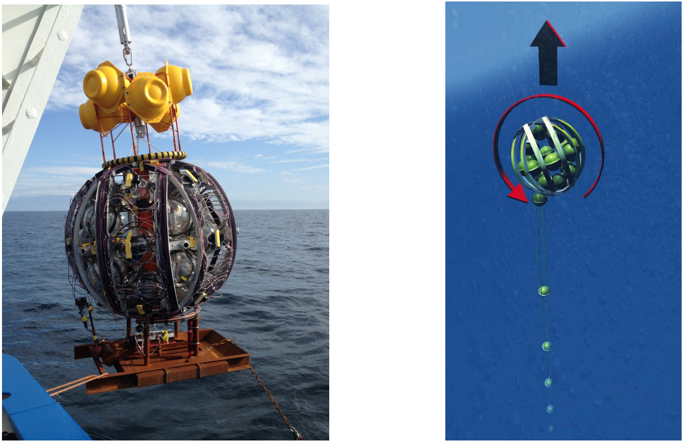


Figure 2: The optical module launching vehicle (LOM) on the boat and during unfurling.

ARCA - Italy

- 2 building blocks of 115 lines of 18 DOMs
- 90m horizontal spacing between lines and 36m vertical spacing between DOMs
- High energy cosmic neutrinos ($10^2 - 10^8$ GeV)

ORCA - France

- 1 building block of 115 lines of 18 DOMs
- 25m horizontal spacing between lines and 9m vertical spacing between DOMs
- Neutrino mass hierarchy measurement and low energy neutrino astronomy ($1 - 100$ GeV)

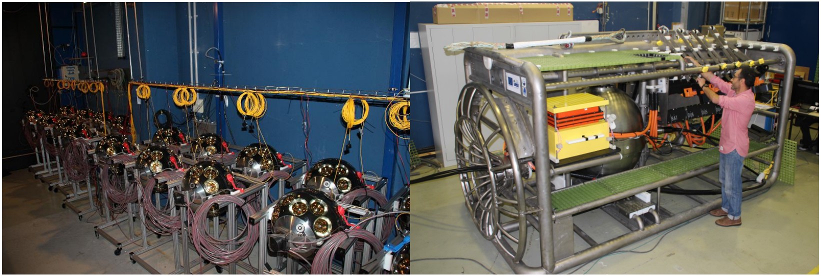


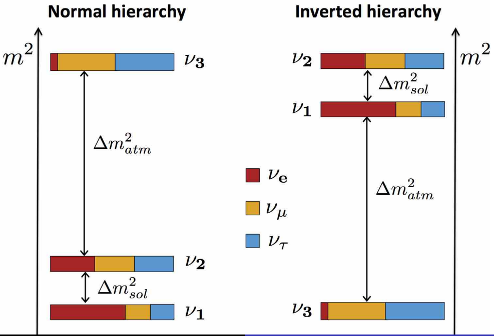
Figure 3: The first ORCA line (left) and the node (right), here at CPPM.

Vacuum Transition Probabilities

$$P_{3\nu}(\nu_\mu \to \nu_e) \approx \sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m^2_{31}L}{4E_\nu}\right)$$

$$P_{3\nu}(\nu_\mu \to \nu_\mu) \approx 1 - 4\cos^2\theta_{13}\sin^2_{23}(1-\cos^2\theta_{13}\sin^2_{23})\sin^2\left(\frac{\Delta m^2_{31}L}{4E_\nu}\right)$$

Normal and Inverted Hierarchies



Due to charged-current elastic scattering interactions with the electrons in matter, it acquires an effective potential

$$A = \pm\sqrt{2} G_F N_e.$$

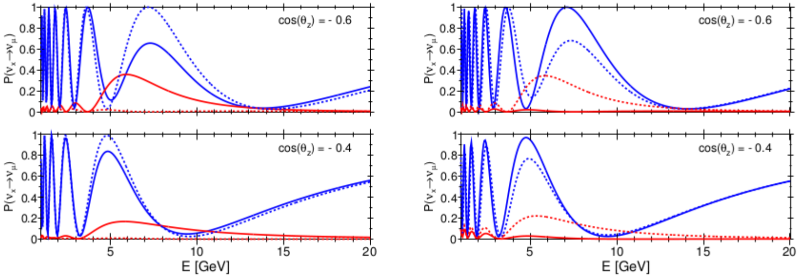


Figure 4: Oscillation probabilities $\nu_\mu \to \nu_\mu$ (blue) and $\nu_e \to \nu_\mu$ as a function of neutrino energy for various zenith angles. The NH (IH) is solid (dashed) and the (anti)neutrinos are on the left (right).

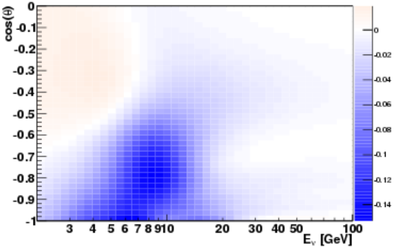


Figure 5: The NMH assymetry, defined as $\frac{N_{IH}-N_{NH}}{N_{NH}}$ for $\nu + \bar{\nu}$ charged current interactions as a function of neutrino energy and cosine zenith angle. Electron neutrinos are on the left and muon neutrinos are on the right. Energy is smeared by 25% and the angle is smeared by $\sqrt{\frac{m_p}{E_\nu}}$.

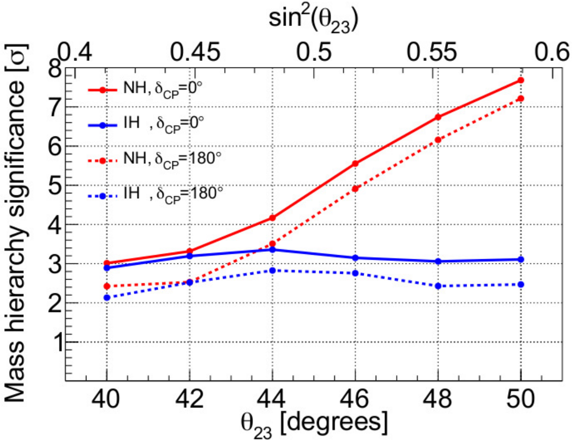
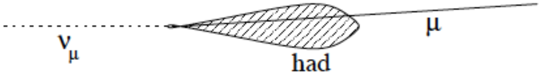


Figure 6: The projected NMH sensitivity for a 115 string ORCA detector, after 3 years, as a function of θ_{23}.

Reconstruction
Muon Tracks

$$\nu_\mu + N \xrightarrow{cc} had + \mu$$



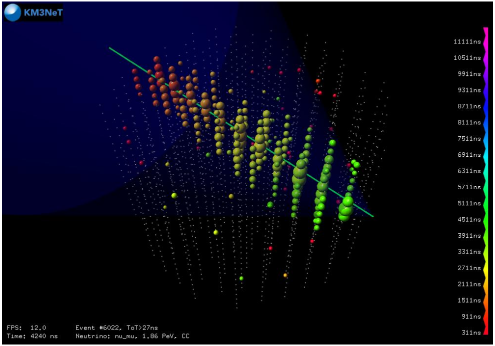


Figure 7: The topography of ν_μ CC interactions in the detector.

Prefit Initially, there are 7 quantities to fit, $\{x, y, z, \delta x, \delta y, \delta z, t\}$

- If you assume a given direction, this reduces down to just $\{x, y, t\}$
- Take 3600 hypothetical directions all over the sky and then pick the best 12

M-Estimator Find the track which minimises $\sum_{\text{hits}} \frac{(t_{\text{true}} - t_{\text{expected}})^2}{\sigma^2}$

- Uses Nelder-Mead minimisation, doesn't use gradient

PDF Fit Incorporates all the known information about the track and detector response

- Find the track which minimises $-\log \mathcal{L}(\text{hits}|\delta t, R, \theta_{\text{PMT}}, \phi_{PMT})$
- Uses the Levenberg-Marquandt algorithm

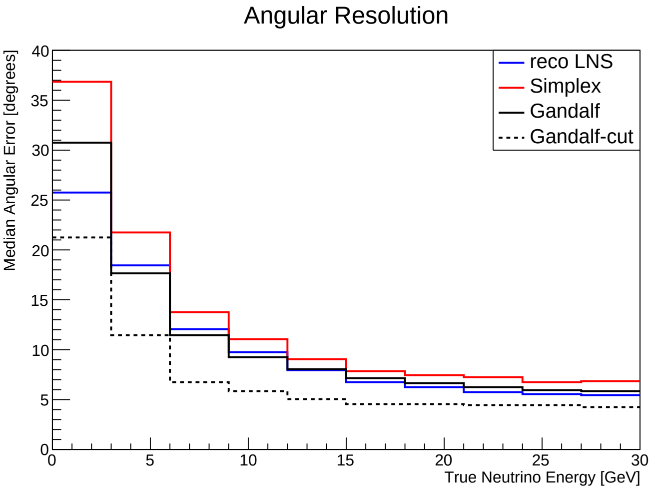


Figure 8: Improved angular resolution on the LoI. Quality cuts were chosen to give the same number of reconstructed events

- Below 100 GeV, $\frac{dE_\mu}{dx} \approx 0.24 \frac{\text{GeV}}{\text{m}}$ - ionisation dominated
  - Muon energy is linearly related to track length
  - Use the hadronic shower to find the track start
- Hadronic states vary, but energy can be fitted using the total light yield
  - Currently, an empirical correction is applied as a function of the total number of hits
  - There is, however, potential to isolate and fit the hadronic shower
- $y = \frac{E_\nu - E_\mu}{E_\nu}$ can also be used to statistically separate neutrinos and antineutrinos
  - $N_\nu \propto 1$
  - $N_{\bar{\nu}} \propto \frac{1}{(y-1)^2}$

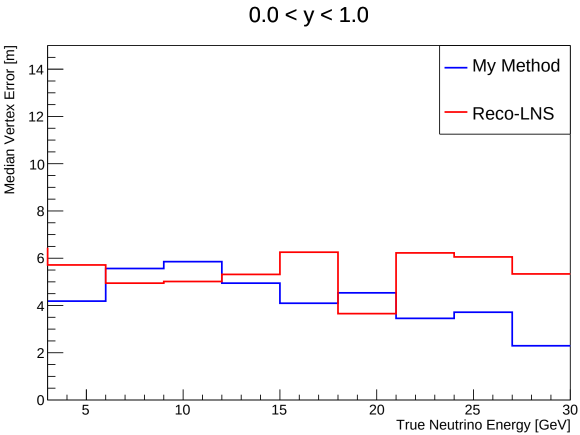


Figure 9: Median vertex error for vertices reconstructed inside the detector, quality cuts chosen for equivalent efficiency.

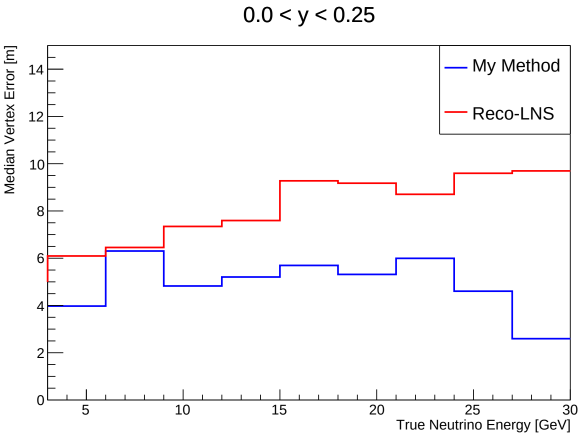


Figure 10: Median vertex error for vertices reconstructed inside the detector, $0 < y < 0.25$, quality cuts chosen for equivalent efficiency.

Currently, once the muon energy is found, one of two empirical corrections is applied based on the number of selected hits.

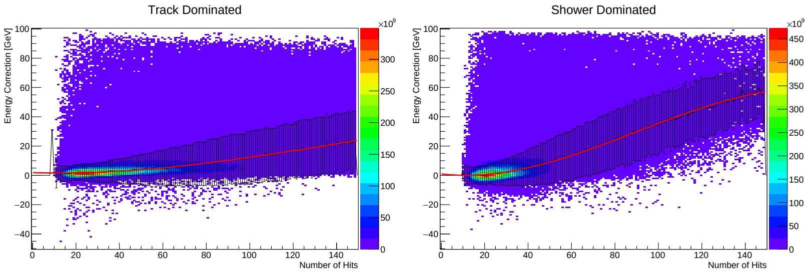


Figure 11: My final correction to the reconstructed muon energy for $y < 0.5$ (left) and $y > 0.5$ (right)

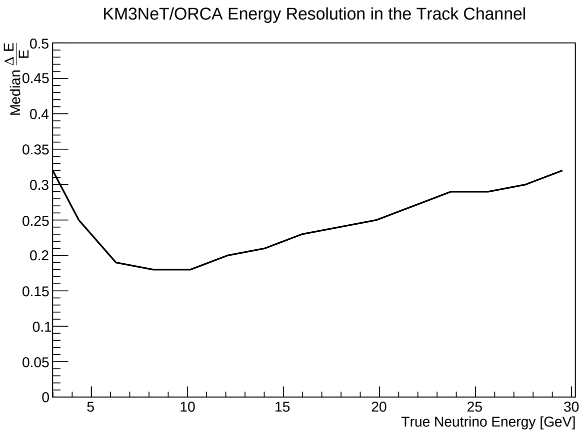


Figure 12: The current median energy resolution for ν_μ CC events as a function of energy.

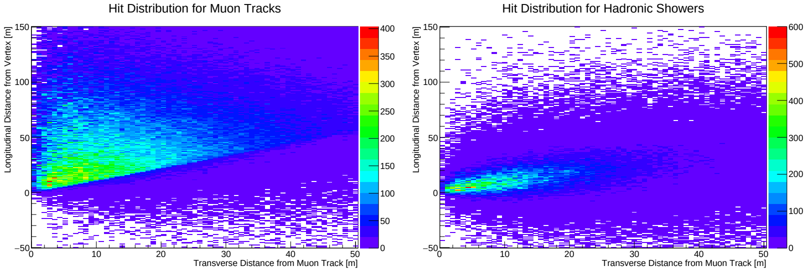


Figure 13: The spatial distribution of track (left) and shower (right) hits with respect to the muon track along the z axis, with the interaction vertex at the origin. Events are taken from the KM3NeT ORCA Montecarlo, in the 3-30GeV range.

Using the spatial distributions shown above, as well as the expected time distribution, we can define:

$$\mathcal{W} = \frac{\mathcal{L}_{\text{shower}}}{\mathcal{L}_{\text{track}} + \mathcal{L}_{\text{shower}} + \mathcal{L}_{\text{K40}}}$$

and then try to find a function $\mathcal{F}$ such that

$$E_{\text{shower}} = \mathcal{F}\left(\sum_{i}^{\text{nhits}} \mathcal{W}_i\right).$$

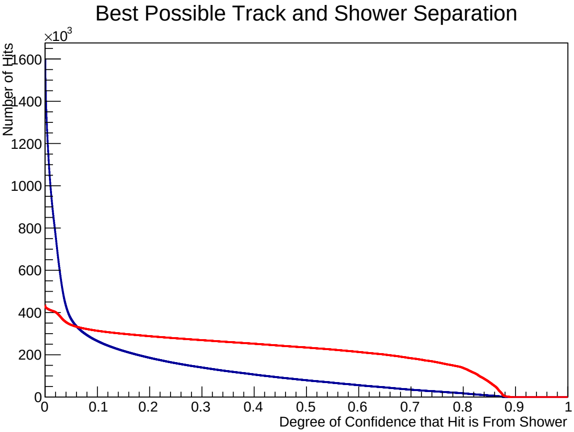


Figure 14: Cumulative plot of confidence that a hit came from a shower and not from the track or K40, in the most optimistic case.

Conclusions

Done

- Created a vertex fit for muon tracks in ORCA
- Created a simple neutrino energy reconstruction

In Process

- Identify the light yield from the hadronic shower and fit its energy separately

In Future

- Try to fit the shower direction
- Study the effect of the bjorken $y = \left(\frac{E_\nu - E_\mu}{E_\nu}\right)$ information on the NMH
- If possible, create simultaneous track and shower fit