Track Reconstruction and Neutrino Mass Hierarchy with KM3NeT

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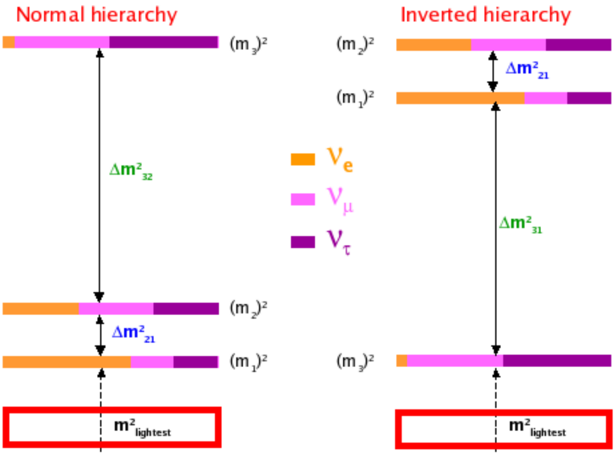

Figure 1: A visual representation of the normal and inverted mass hierarchies.

Vacuum Transition Probability

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

Transition Probability Through a Medium with Constant Density

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

where

$$\Delta^m m^2 = \sqrt{(\Delta m^2_{31}\cos 2\theta_{13} \mp 2E_\nu \underline{\underline{\sqrt{2}G_F N_e}})^2 + (\Delta m^2_{31}\sin 2\theta_{13})^2}$$

which is resonant when $\Delta^m m^2$ is minimised.
$E_\nu \sim$ 7GeV (crust) and 3GeV (mantle).

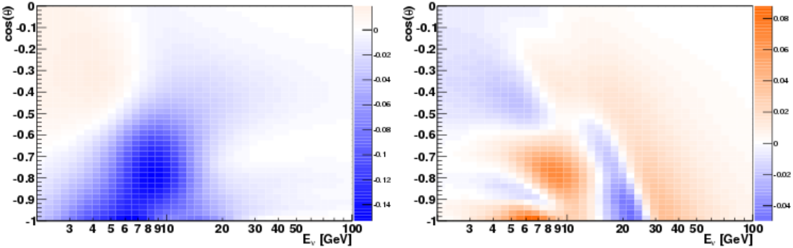

Figure 2: The NMH assymetry, defined as $\frac{N_{IH}-N_{NH}}{N_{NH}}$ for $\nu+\bar{\nu}$ charged current interactions as a function of neutrino energy and cosine zenith angle. Electron neutrinos are on the left and muon neutrinos are on the right. Energy is smeared by 25% and the angle is smeared by $\sqrt{\frac{m_p}{E_\nu}}$.

If a charged particle moves faster than the speed of light through a medium, it creates a distinctive disturbance or shockwave known as Čerenkov radiation.

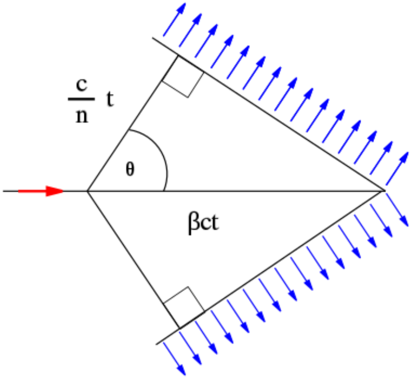

Figure 3: A diagram showing the geometry of Čerenkov radiation.

Digital Optical Module (DOM)

- Glass sphere, diameter 17 inches ($\sim$ 40 cm)
- Contains 31 3 inch ($\sim$ 7.5 cm) photo-multiplier tubes (PMTs)
- Equipped with a tiltmeter, compass and temperature and humidity sensors

ARCA - High Energy

- Off the coast of Portopalo di Capo Passero in Sicily
- A vertical separation of 36m and a horizontal separation of 90m

ORCA - Low Energy

- Off the coast of Toulon in the South of France
- A vertical separation of 9m and a horizontal separation of 20m

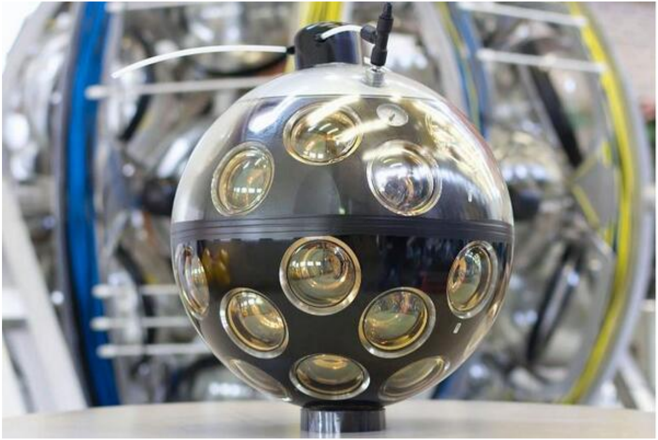

Figure 4: The KM3NeT digital optical module (DOM).

Detection Principle
Detector Layout

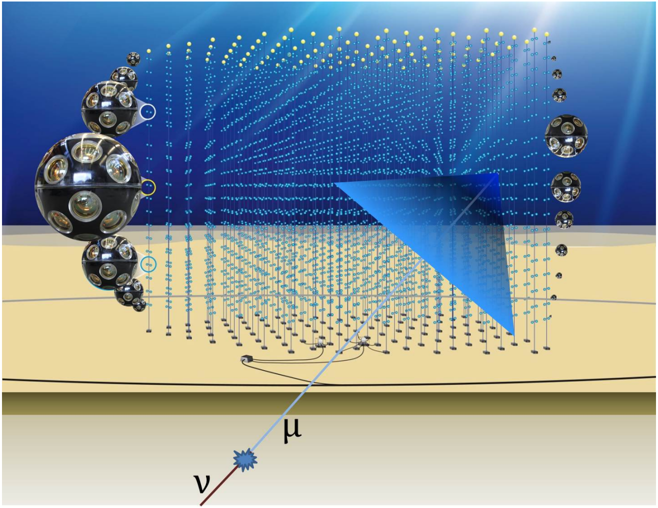

Figure 5: An artist's impression of the KM3NeT telescope array.

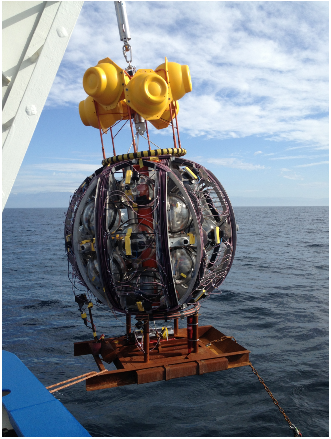

Figure 6: The optical module launching vehicle (LOM) on the boat and during unfurling.

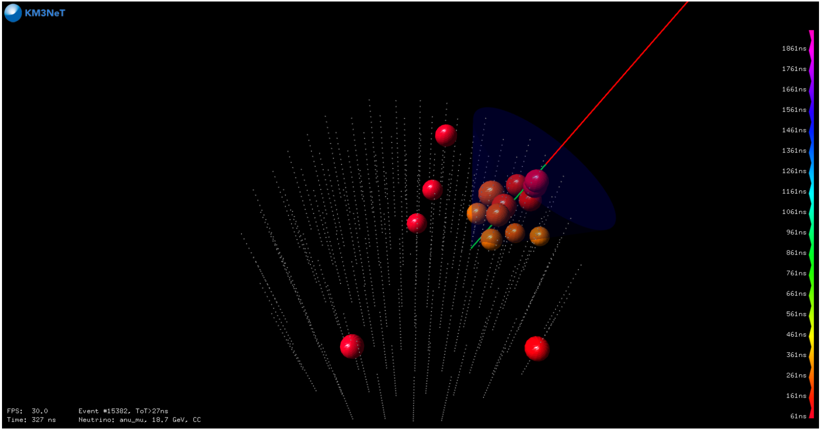

Figure 7: A simulated 19 GeV antineutrino event in ORCA, with the antineutrino in red and the antimuon in green.

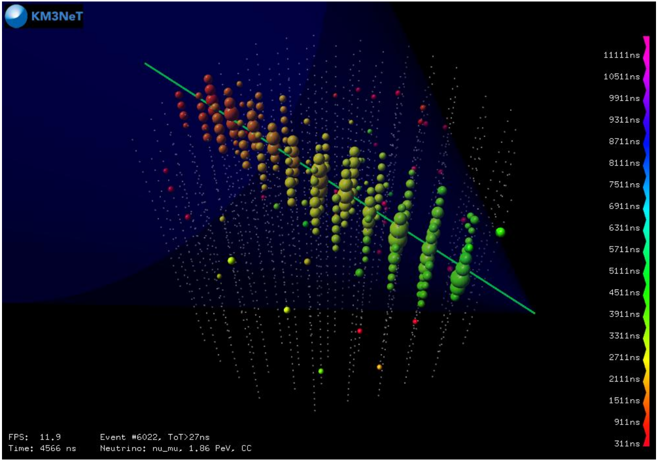

Figure 8: A simulated 1.9 PeV neutrino event in ARCA, with the neutrino in red and the antimuon in green.

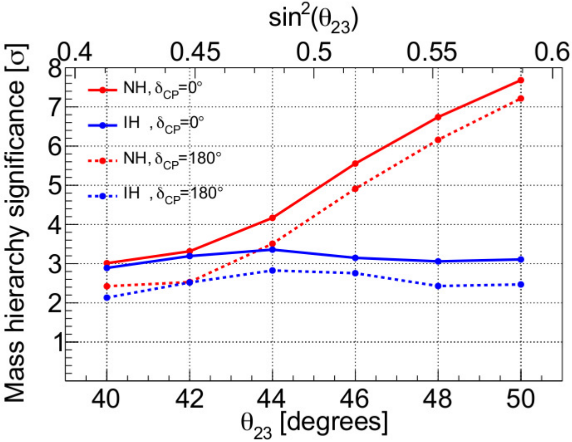

Figure 9: The projected NMH sensitivity for a 115 string ORCA detector, after 3 years, as a function of θ_{23}.

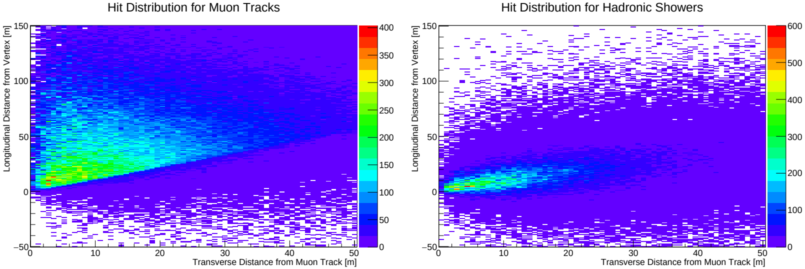

Figure 10: The spatial distribution of track (left) and shower (right) hits with respect to the muon track along the z axis, with the interaction vertex at the origin. Events are taken from the KM3NeT ORCA Montecarlo, in the 3-30GeV range.

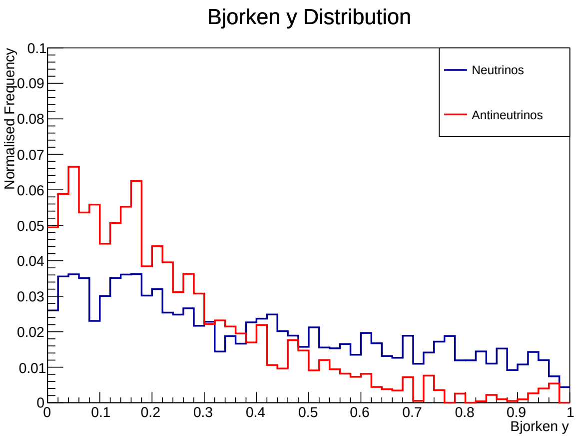

Figure 11: The distribution of Bjorken y, defined as $\frac{E_\nu - E_\mu}{E_\nu}$, for neutrinos and antineutrinos. The difference is due to handedness, with $\sigma_\nu^{cc} \propto 1$ and $\sigma_{\bar{\nu}}^{cc} \propto (1-y)^2$.

How much time to do we have left?

Objective Find $\{x, y, z, \delta x, \delta y, \delta z, t\}$ using hit times and positions

Prefit

- Take 3600 track direction hypotheses across the entire sky
- For each hypothesis, the problem reduces to finding $\{x, y, t\}$
- Pick a small number of solutions with the best χ^2

Simplex fit

- Assume $t_{\text{hit}} - t_{\text{expected}}$ is normally distributed
- Find minimum χ^2 using downhill simplex fit

PDF fit

- Use likelihood which incorporates absorption, scattering and PMT response
- Find maximum using the Levenberg Marquandt algorithm

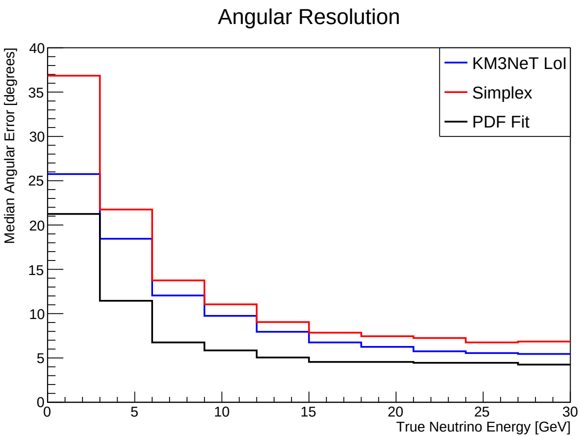

Figure 12: The latest angular resolution with ORCA, defined with respect to the true *neutrino* direction. At lower energies, the muon and neutrino are less likely to be colinear, adversely affecting the resolution.

We know that

- The interaction vertex can be found by looking for the hadronic shower
- At low energies, muon energy is directly proportional to track length
- The rest of the muon energy goes into the hadronic shower and the nucleus

therefore

- We need to extract as much information (energy and direction) from the hadronic shower as we can, to build a more complete picture of ν_μ CC interactions within ORCA

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Thanks for listening