ICRC 2015

ERLANGEN CENTRE FOR ASTROPARTICLE PHYSICS

Reconstruction of shower-like neutrino events with the KM3NeT/ORCA detector

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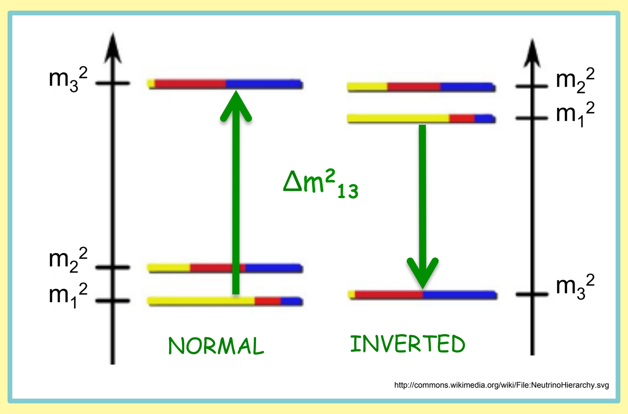
Measuring the neutrino mass hierarchy with atmospheric neutrinos

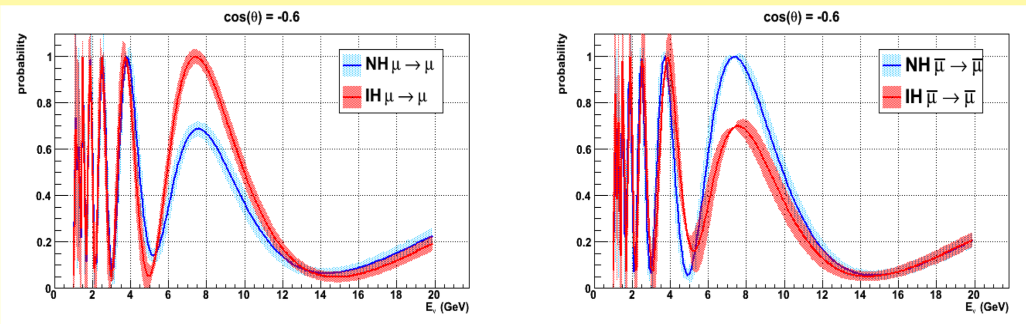
All neutrino oscillation parameters can be extracted from global fits. The relatively large value of θ_{13} (drives $\nu_e \leftrightarrow \nu_\mu$ oscillation) is beneficial for the determination of the remaining unknown neutrino parameters: CP-violating phase δ_{CP} and **neutrino mass hierarchy** (NMH: normal or inverted).

Standard strategy for NMH determination: probe $\nu_e \leftrightarrow \nu_\mu$ oscillation in presence of matter effects. *E. Akhmedov et al., JHEP 02 (2013), 082*

Oscillation enhancement is maximal at resonant energy:

$E_{res} \sim 30\text{GeV} / \rho\ [\text{g cm}^{-3}]$ **$E_{res} \approx$ few GeV for Earth matter density: good prospects for atmospheric neutrinos!**





$P(\nu_\mu \rightarrow \nu_\mu, \text{NH}) = P(\bar{\nu}_\mu \rightarrow \bar{\nu}_\mu, \text{IH})$

But other ingredients create a difference in number of events for IH vs. NH:

- (anti-)neutrino cross-section: $\sigma_{\nu N} \approx 2\sigma_{\bar{\nu}N}$
- atmospheric (anti-)neutrino fluxes

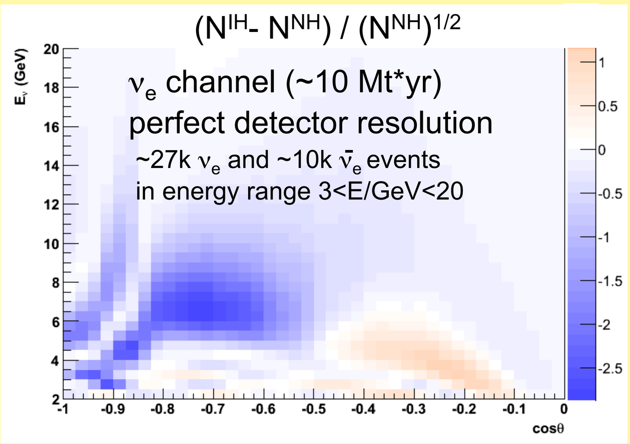
Distinctive pattern in **energy E_ν and zenith θ_ν oscillograms** shows difference for NH and IH

Main challenges:

- **NH/IH difference intrinsically small**
- **oscillograms blurred by limited E_ν and θ_ν accuracy**
  → **accurate reconstruction essential**

Possible gain in NMH sensitivity due to $\nu / \bar{\nu}$ separation based on different Bjorken-y distributions: $\langle y_\nu \rangle \approx 0.5$, $\langle y_{\bar{\nu}} \rangle \approx 0.3$

M. Ribordy et al., Phys.Rev. D87 (2013) 113007

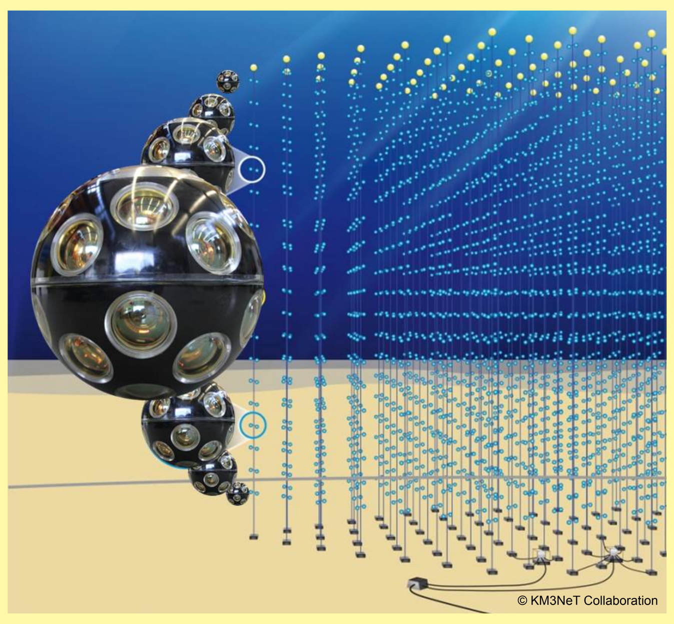


KM3NeT/ORCA (Oscillation Research with Cosmics in the Abyss): a dense neutrino detector in the Mediterranean Sea

KM3NeT is the next-generation underwater neutrino telescope in the Mediterranean Sea with two detectors:

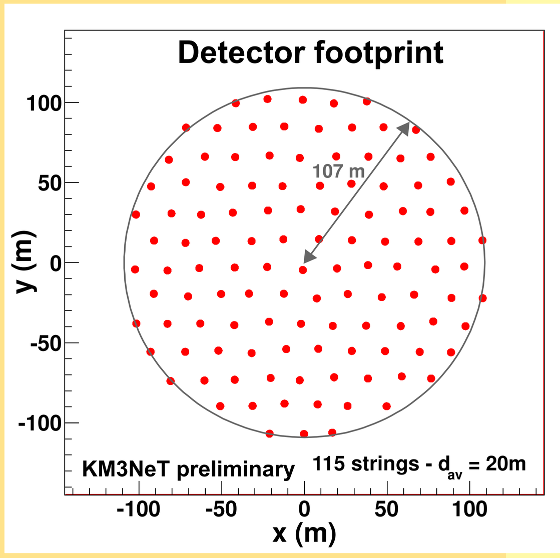
- **ORCA** → NMH determination ➡ *talk by J. Brunner*
- ARCA → high-energy neutrino astronomy ➡ *talk by P. Piattelli*

- same detection principle: Cherenkov light emitted by secondary particles produced in neutrino interactions
- **same technology and detector design:** instrumented lines anchored at the seabed and supporting multi-PMT digital optical modules (DOMs) ➡ *poster by R. Bruijn*
- **denser array for ORCA to lower threshold to ~GeV**
- line spacing & length limited by deployment constrains



Proposed detector:

- location: 40km offshore from Toulon, France, at 2475m depth
- 115 strings, 20m spaced
- 18 DOM/string, 6-18m spaced
- instrumented volume: 3.6 – 10.8 x 10^6 m^3
- detector optimisation ongoing



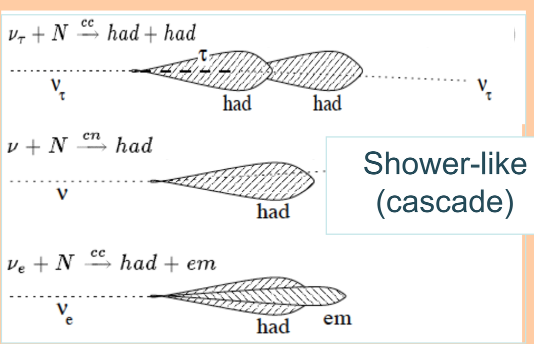
Simulation

- atmospheric $\nu_e + \nu_\mu$ (+anti) flux: Bartol *Agrawal et al., PRD 53, (1996) 1314*
- neutrino interaction: GENIE *Andreopoulos et al., Nucl. Instrum. Meth. A614 (2010), 87-104*
- particle propagation: GEANT *Agostinelli et al., Nucl. Instrum. Meth. A506 (2003), 250-303*
- Cherenkov light emission and photon propagation in seawater
- optical background (^{40}K decays)

Shower Phenomenology

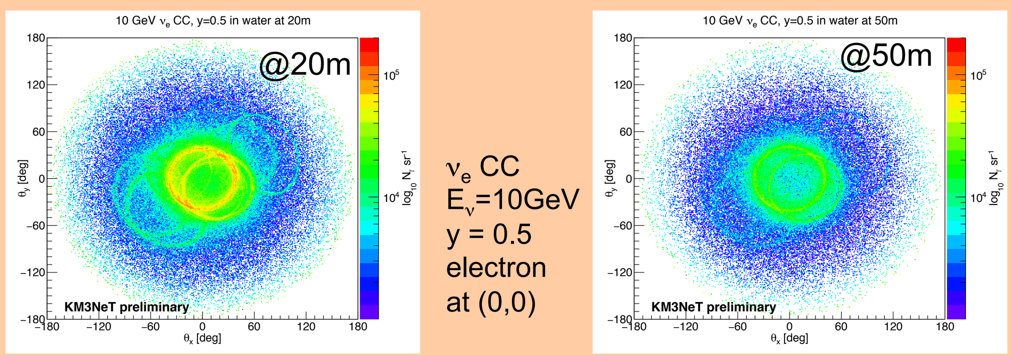
Showers are:

- cascades of energetic particle
- initiated by $\overset{(-)}{\nu}_e$ CC, $\overset{(-)}{\nu}$NC and $\overset{(-)}{\nu}_\tau$ CC with non-muonic τ decays
- electrons → electromagnetic shower
- hadrons → hadronic shower



Light emission characteristics:

- point-like light burst
- Cherenkov ring from each energetic particle
- had. showers:
  - smaller light yield than el.mag. showers
  - large event-by-event fluctuations ➡ *poster by J. Hofestädt*

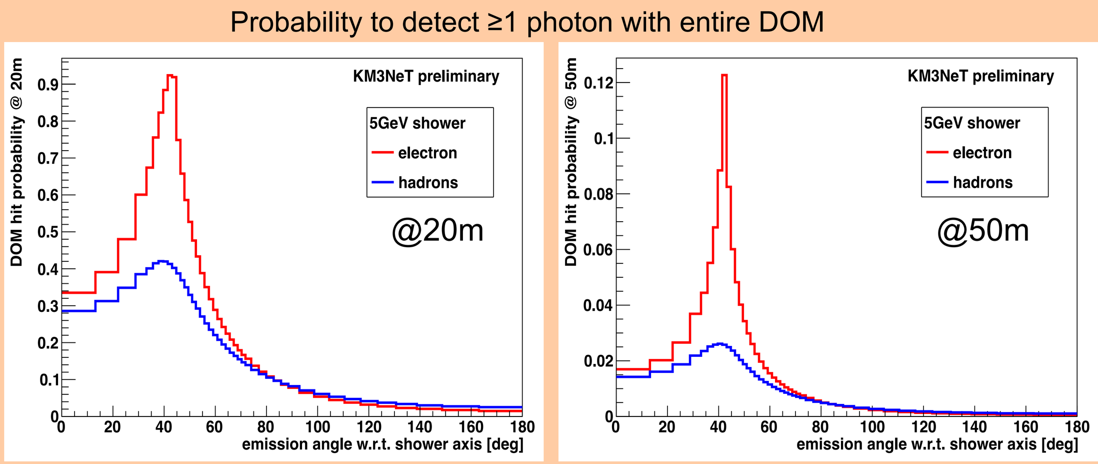


Signatures:

- **emission characteristics conserved over large distances due to large scattering length in water**
- broader angular light distribution for had. than for el.mag. showers
- $\overset{(-)}{\nu}_e$ CC events:
  - overlapping el.mag. & had. shower
  - mostly electron is brightest particle

  → **estimation of inelasticity feasible**

Probability to detect ≥1 photon with entire DOM

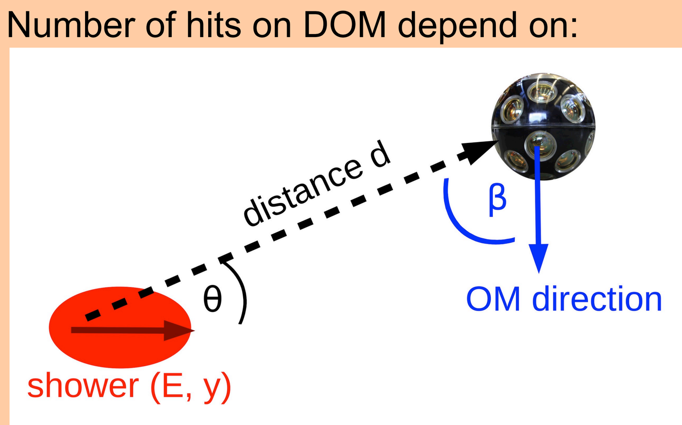


Reconstruction Methodology

Consecutive fitting procedure:

- 1. vertex: based on hit times (assuming spherical shower)
- 2. energy & direction & y: based on number of hits and their distribution in detector

Number of hits on DOM depend on:

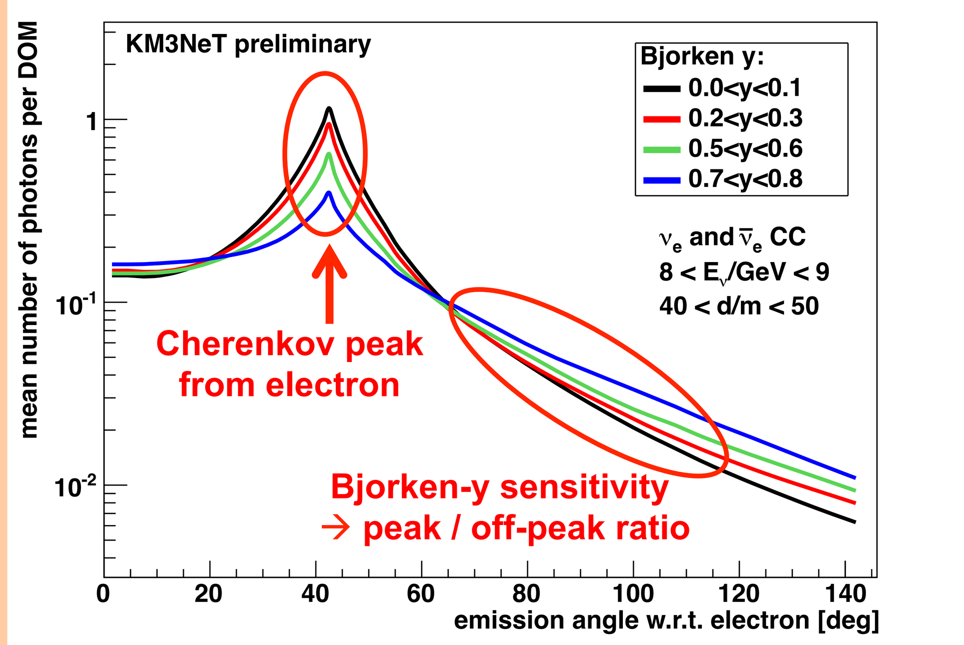


Energy & direction & y reconstruction:

- designed to find brightest particle (→ electron in most ν_e CC events)
- maximum likelihood method
- PDF tables obtained from MC simulations of $\overset{(-)}{\nu}_e$ CC event

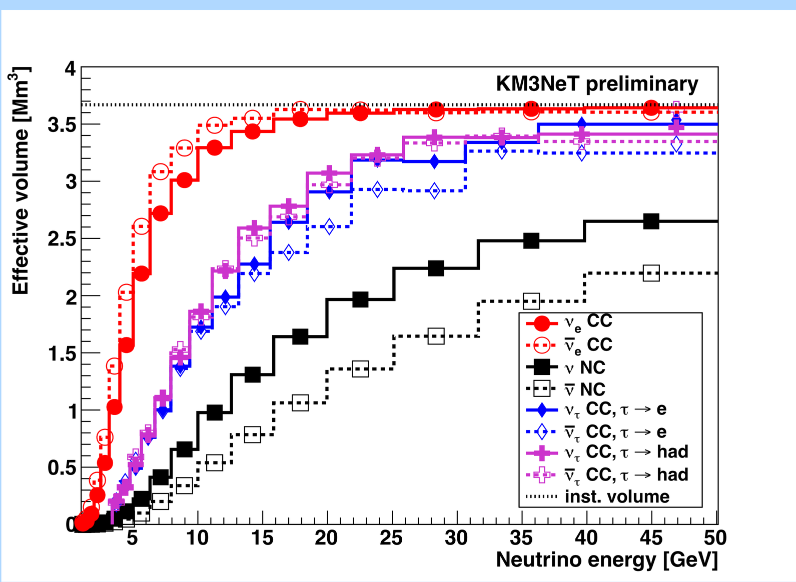
- Fit parameter sensitivity:
- integral → total light yield → energy
- shape → shower type → Bjorken-y
- brightest Cherenkov ring → direction

PDF used in reconstruction



Reconstruction Performance

Effective volume

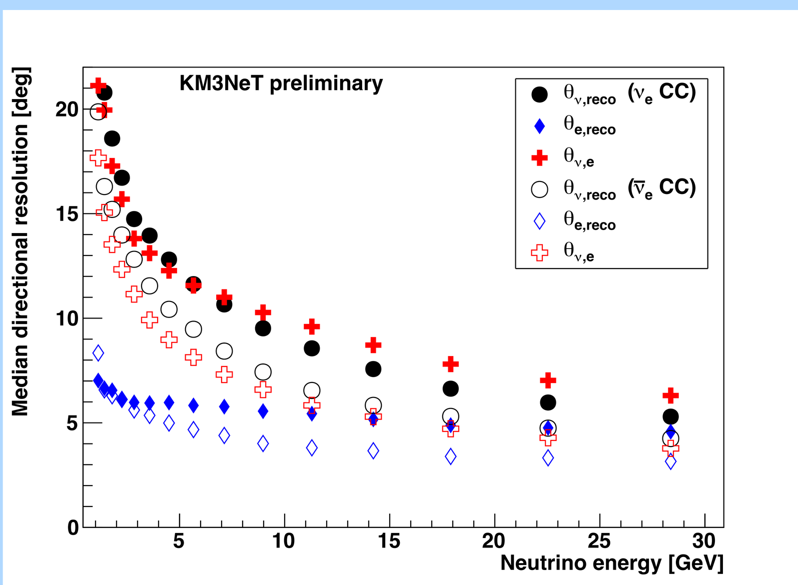


- plateau close to instrumented volume

Plots for upgoing neutrino events (unoscillated Bartol flux) and for ORCA detector with 6m vertical spacing

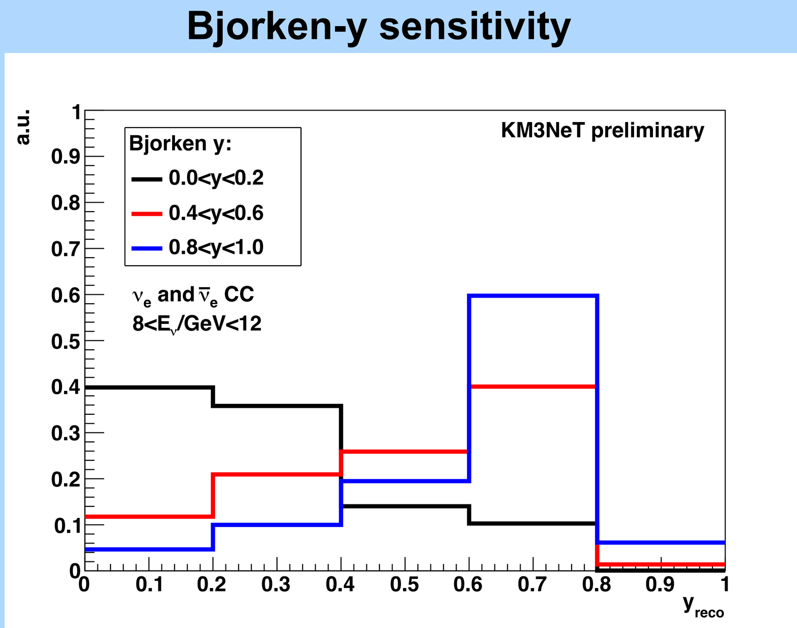
Events selected according to reconstruction quality and containment criteria

Direction resolution



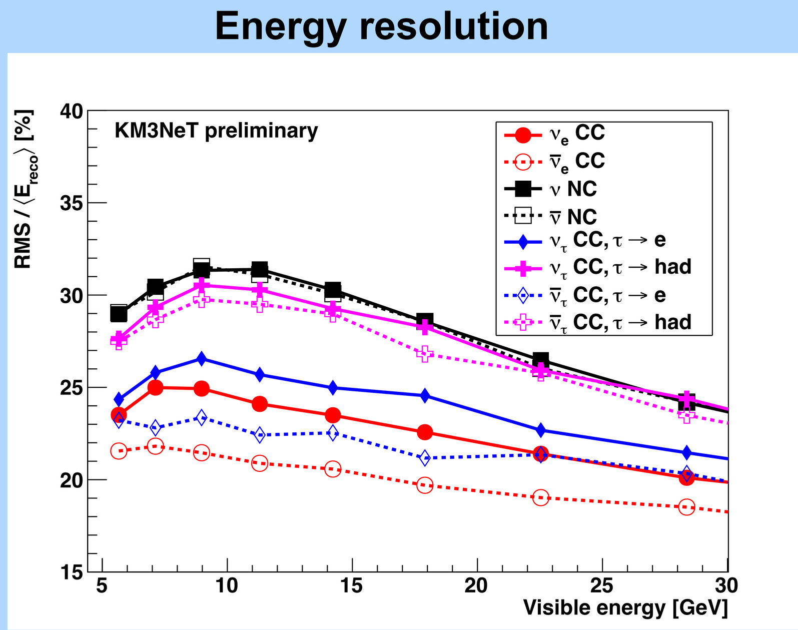
- **reconstruction finds electron in $\overset{(-)}{\nu}_e$ CC events**
- Median $\theta_{\nu,reco}$ resolution better than 10° for $E_\nu \geq$ 8(5)GeV in ν_e ($\bar{\nu}_e$) CC events

Bjorken-y sensitivity



- Bjorken-y sensitivity allows
  - to account for different light yields in energy reconstruction
  - separation on statistical basis between ν_e CC, $\bar{\nu}_e$ CC and $\overset{(-)}{\nu}$NC

Energy resolution



- **Gaussian energy resolution with RMS / $\langle E_{reco} \rangle$ better than 25% (22%) for $E_\nu \geq$ 7GeV in ν_e ($\bar{\nu}_e$) CC events**
- 'visible energy' = difference between incoming & outgoing neutrino(s) from primary ν interaction or τ-decay

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