Depth dependence with the first two KM3NeT/ARCA Detection Units

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Related posters
[1] K. Melis, In-Situ Calibration of KM3NeT
[2] M. Colomer, D. Dormic, V. Kulikovskiy, Detailed KM3NeT optical module simulation with Geant4 and supernova neutrino detection study
KM3NeT

• See previous talk by K. Melis
• Cubic kilometer neutrino telescope
• Mediterranean sea
• Oscillation/Astroparticle Research with Cosmics in the Abyss
  • ORCA: atmospheric neutrino oscillation
  • ARCA: high-energy cosmic neutrino sources
• Construction ongoing
Detection Unit (DU) or “string”
Consists of 18 DOMs

Digital Optical Module (DOM)
Contains 31 3” PMTs

KM3NeT
ARCA Detection Unit to scale

Floor 3, height ~141 m
Floor 2, height ~103 m
Floor 1, height ~65 m

Each • represents a DOM such as the one shown in this picture.

Assuming 173.5 cm for scale

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First two ARCA Detection Units

- **ARCA-DU1 and ARCA-DU2**
  - first two full KM3NeT DUs or “strings”
  - deployed December 2015 and May 2016 at Capo Passero, Sicily
  - 37 m inter-DOM spacing

- **Data sample used in this analysis**
  - 19.5 days of ARCA-DU1 + ARCA-DU2 data
  - 23 December 2016 to 13 January 2017
  - plenty of statistics
Atmospheric muon flux depth dependence

• Goals
  – test data/MC agreement
  – eventually: muon flux measurement over depth range

• Atmospheric muons
  – **Background** for neutrino physics
  – Useful for in-situ calibration: DOM time offsets, see poster K. Melis [1]
Local coincidences

- Signal selection
  - using DOM as standalone unit
  - possible thanks to multi-PMT technology
- $^{40}$K decay
  - photons hit few PMTs
  - useful for in-situ calibration, see poster by K. Melis [1]
- Atmospheric muons
  - photons can hit many PMTs

“m-fold coincidence” or “multiplicity m coincidence” := m PMTs hit on a DOM within 25 ns
Local coincidences

Cut $m \geq 8$ selects atmospheric muon signal

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Local coincidences

$^{40}$K MC: see posters by M. Colomer [2], K. Melis [1]

note: $^{40}$K MC scaled to data within systematic uncertainties.
Local coincidences

Note larger muon contribution

KM3NeT/ARCA preliminary

Exlusive m-fold coincidence rate [Hz]

10^4

10^3

10^2

10^1

10^0

10^{-1}

10^{-2}

10^{-3}

10^{-4}

10^{-5}

10^{-6}

10^{-7}

multiplicity m

S1F1 (data)

S2F18 (data)

S1F1 (muon MC)

S2F18 (muon MC)

S1F1 (K40 + muon MC)

S2F18 (K40 + muon MC)

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PMT efficiencies

- Each PMT is slightly different
- PMT efficiency
  - performance compared to the MC PMT model
  - measured in-situ using $^{40}\text{K}$ decays, see poster by K. Melis [1]
  - input for MC simulation

Example figures from [1]
Data/MC comparison

- Correction factor applied to each data point:

MC rate (uniform efficiencies)

MC rate (measured efficiencies)

- Efficiencies from in-situ calibration improve data/MC agreement

- Statistical error bars too small to be visible

Decrease by a factor $\sim 2$ over 630 m
Muon MC studies

- Single muon MC events
- Signal muons pass by very close to the DOM

Using MUPAGE atmospheric muon generator, see proceedings for more details
Muon MC studies

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- Single muon MC events
- Muon energy increases with multiplicity

Using MUPAGE atmospheric muon generator, see proceedings for more details
Muon MC studies

• ~13% of the generated events is a **muon bundle**, i.e. contains >1 muon
• Bundle muons are close together: median distance to leading muon is 8 m

Using MUPAGE atmospheric muon generator, see proceedings for more details
Conclusions and outlook

- Depth dependence of high-multiplicity rates measured with ARCA-DU1 and ARCA-DU2
- Excellent data/MC agreement
- In-situ measured PMT efficiencies improve data/MC agreement
- Signal characteristics studied in MC
- Outlook
  - compare different atmospheric muon generators (MUPAGE, CORSIKA)
  - investigate systematics
  - translate to measurement of atmospheric muon flux over depth range
Backup slides
Depth dependence

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Depth dependence
Monte Carlo simulations

- Atmospheric muons
  - MUPAGE “fast muon generator for neutrino telescopes based on parametric formulas”
- Generation and propagation of light using KM3 and JPP
- Uses in-situ calibrated PMT efficiencies