Depth dependence with the first two KM3NeT Detection Units

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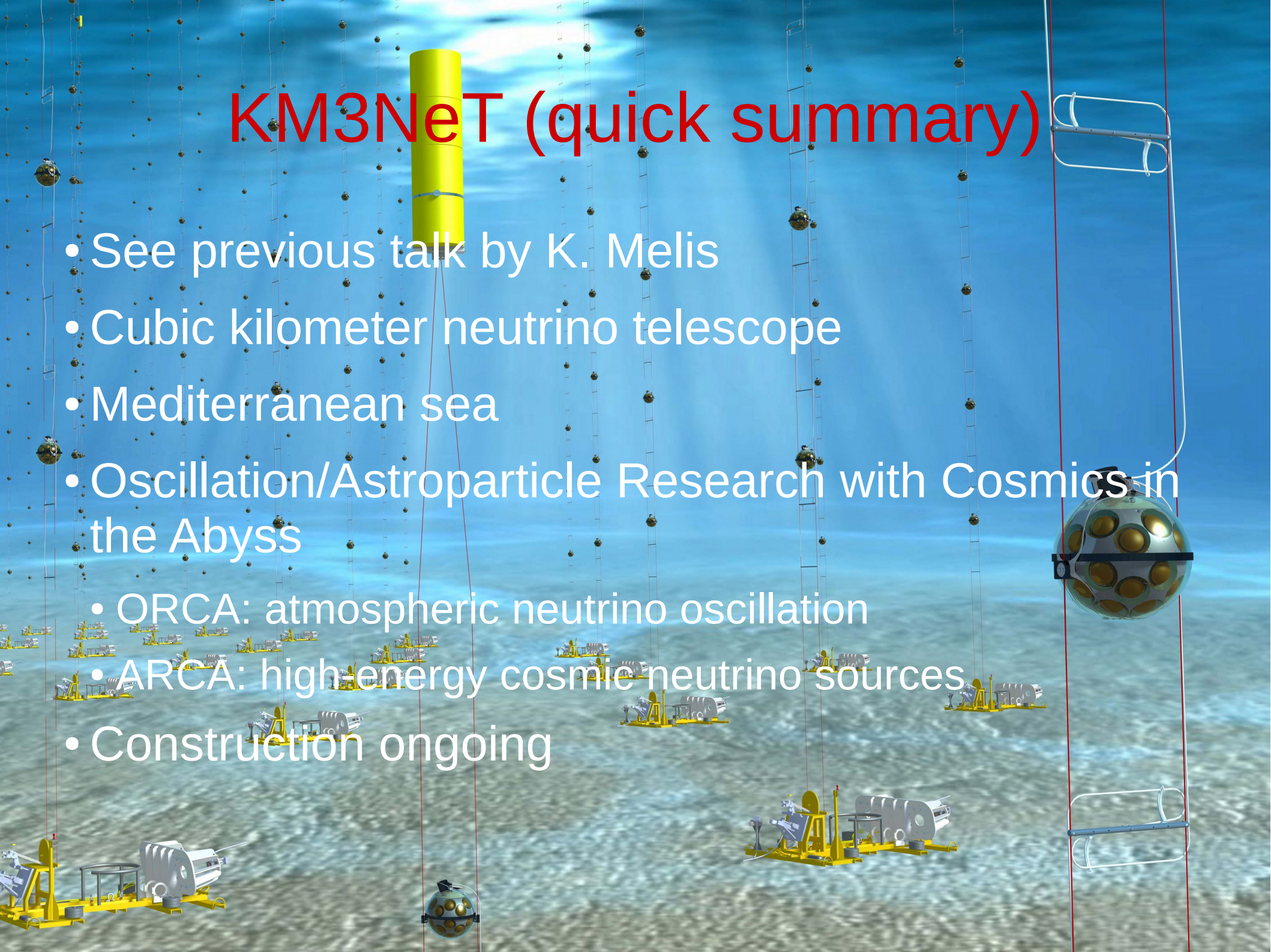
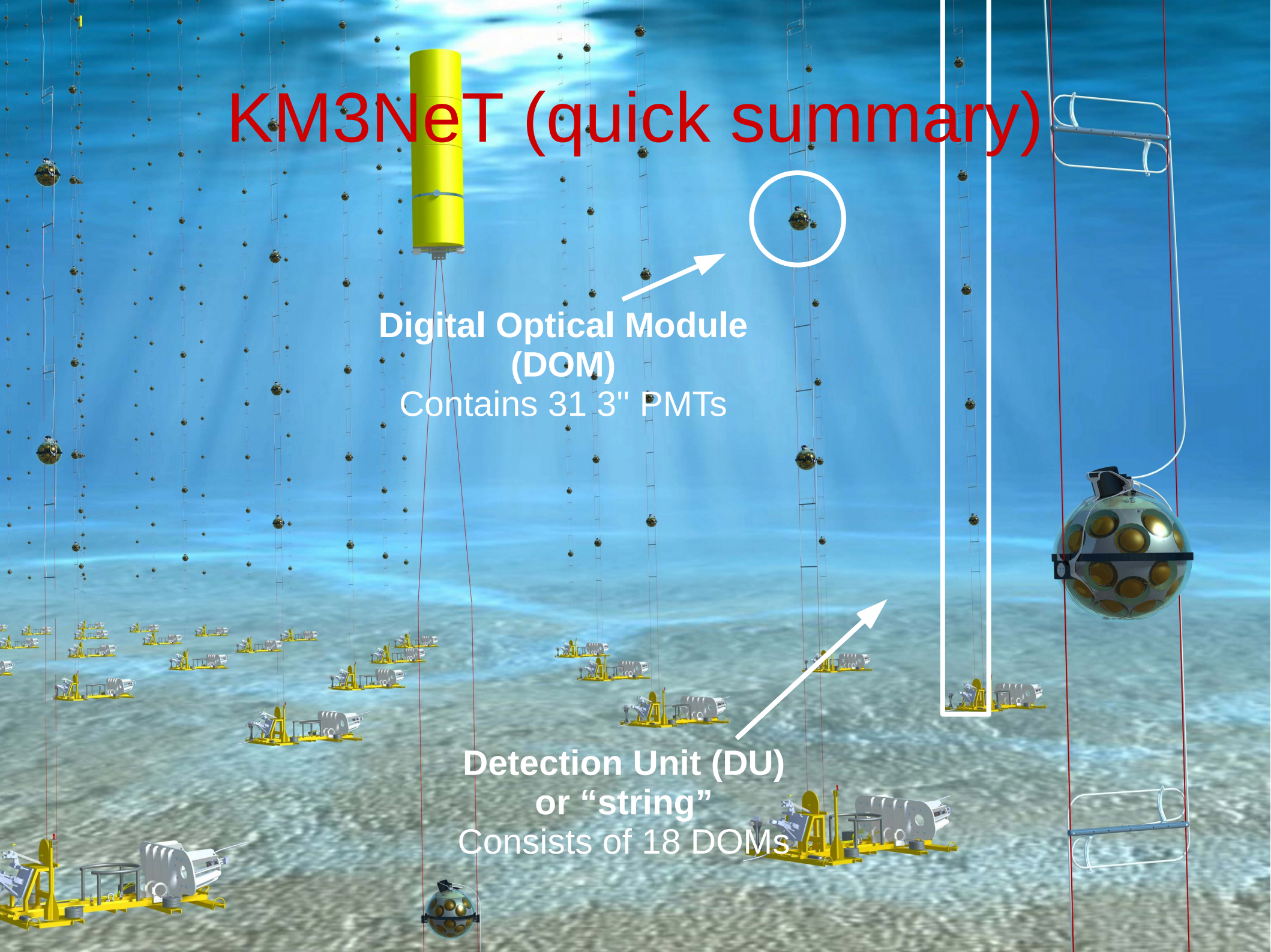
KM3NeT (quick summary)

- 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




KM3NeT (quick summary)
Digital Optical Module (DOM)
Contains 31 3" PMTs
Detection Unit (DU) or “string”
Consists of 18 DOMs

First two ARCA Detection Units

- ARCA-DU1 and ARCA-DU2
  - first two full KM3NeT DUs or “strings”
  - deployed December 2015 and May 2016
  - Capo Passero, Sicily
- Data sample used in this analysis
  - 19.5 days of ARCA-DU1 + ARCA-DU2 data
  - 23 December 2016 to 13 January 2017

KM3NeT deployment sites. Capo Passero, the location of ARCA-DU1 and ARCA-DU2, is indicated.

Detection Unit to scale

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

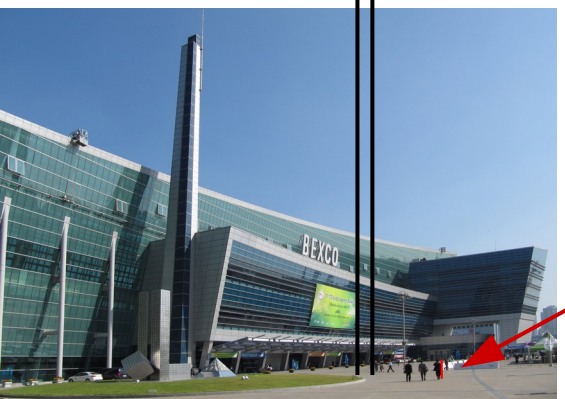
Height difference 630 m between floor 1 and floor 18.

Up to floor 18

Floor 3, height ~141 m

Floor 2, height ~103 m

Floor 1, height ~65 m



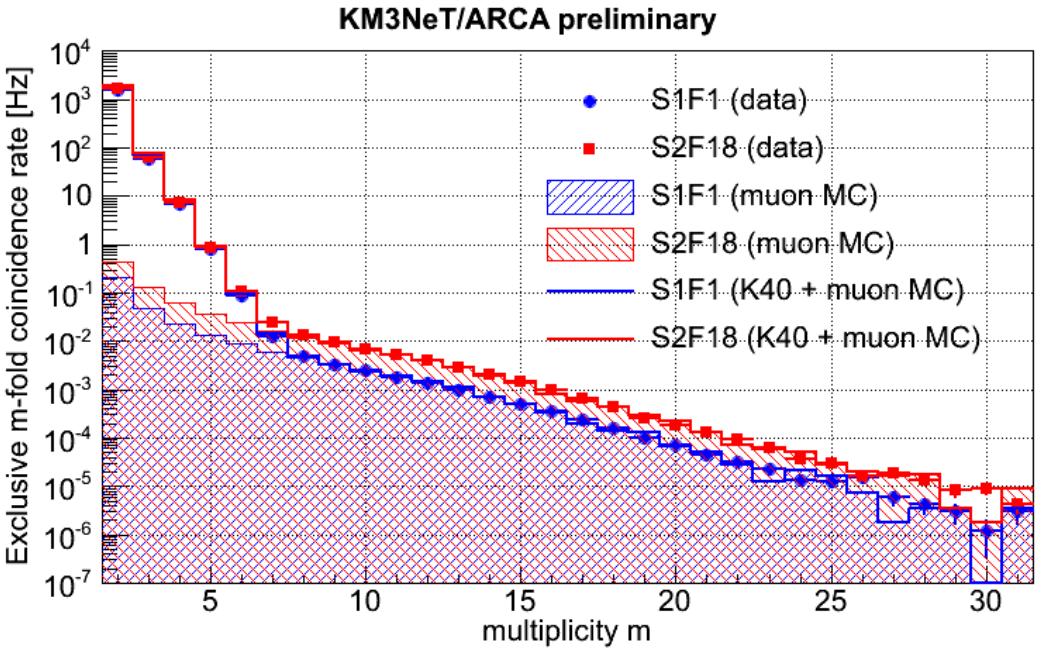
Assuming 173.5 cm for scale

Muon flux depth dependence

- Atmospheric muons created in cosmic ray air showers
- Penetrate to large depths
- Background for neutrino searches
- Useful for in-situ calibration

Local coincidences

- [Show illustration of DOM with three sources of signal: atmospheric muons, K40 and bioluminescence]
- 25 ns window
- m-fold or multiplicity m coincidence: m PMTs hit on a DOM within a 25 ns time window

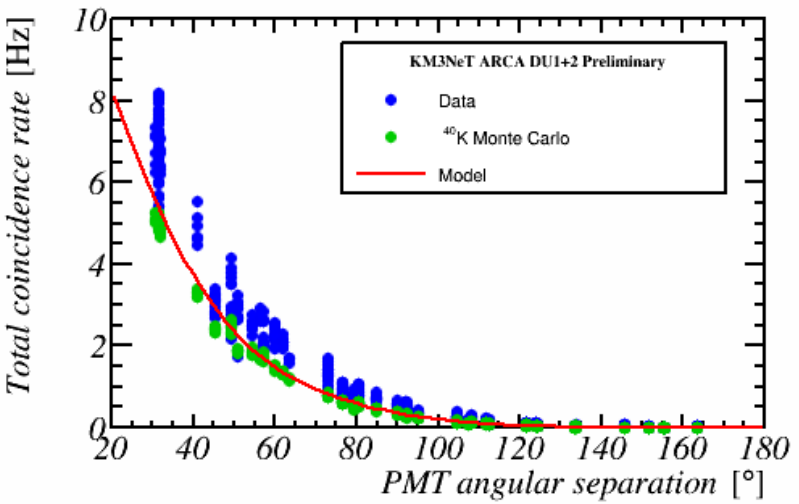


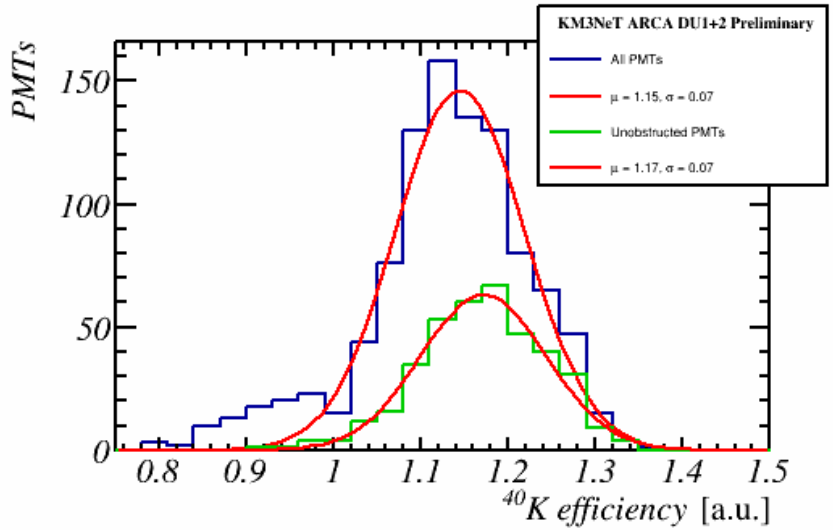
Monte Carlo simulations

- K-40 background: OMGsim
  - see …
- Atmospheric muons
  - MUPAGE “fast muon generator for neutrino telescopes based on parametric formulas”
- Generation and propagation of light using KM3 and JPP
- Use in-situ calibrated **PMT efficiencies**

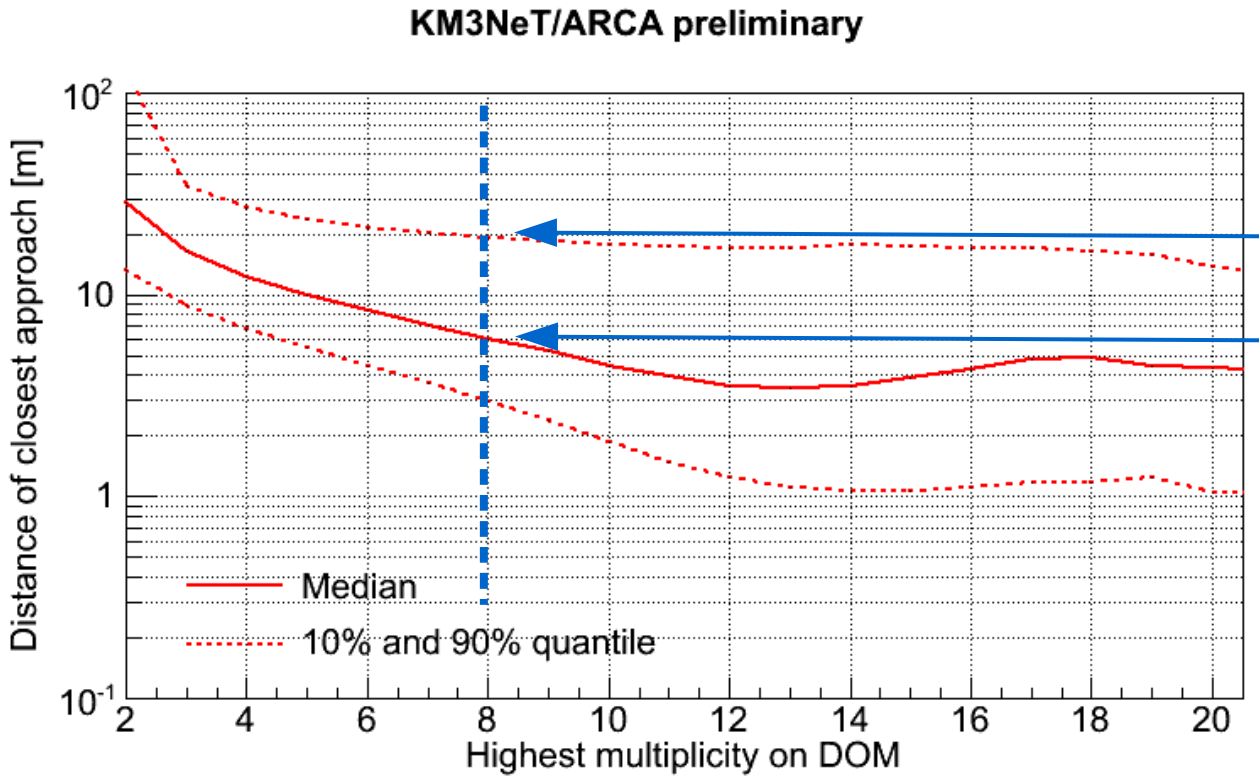
PMT efficiencies

- number for each PMT
- quantifies how well it performs compared to the MC PMT model
- based on in-situ calibration
- see “In-situ Calibration of KM3NeT” poster by K. Melis





Distance of closest approach

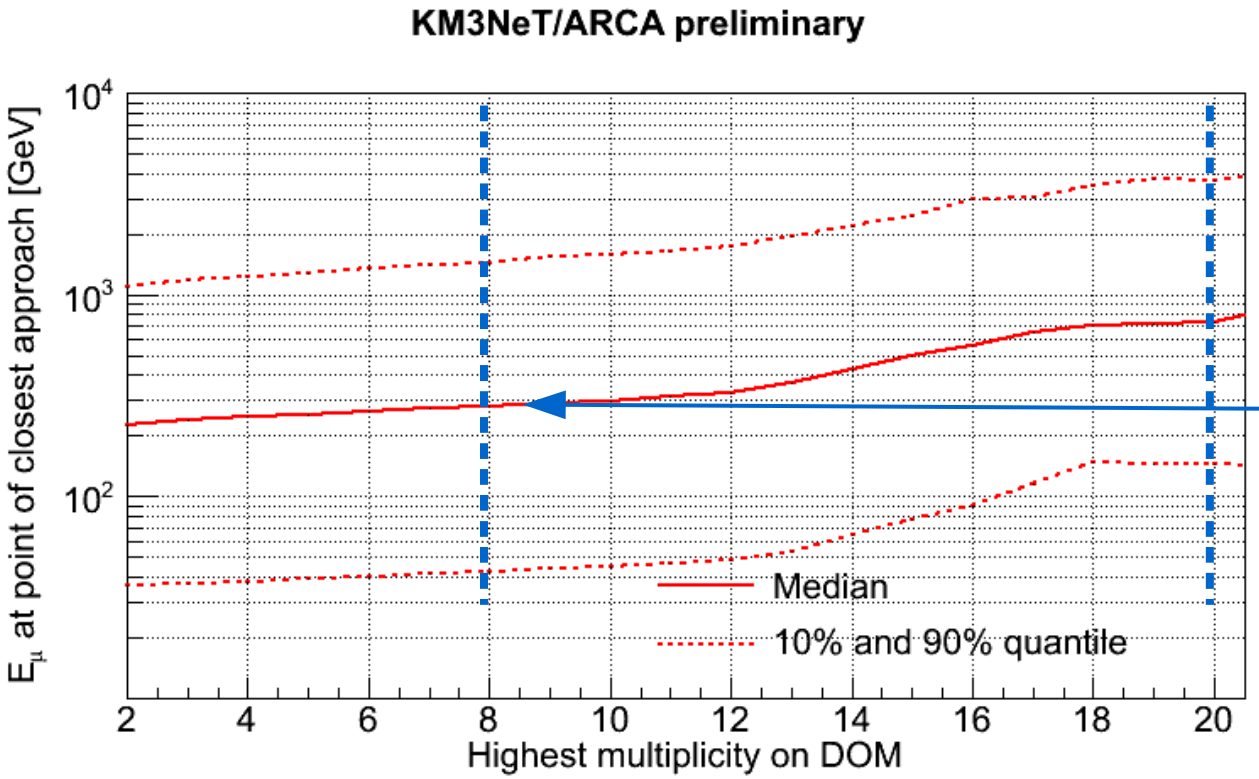


90% closer than 20 m

median DCA 6 m

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

Muon energy



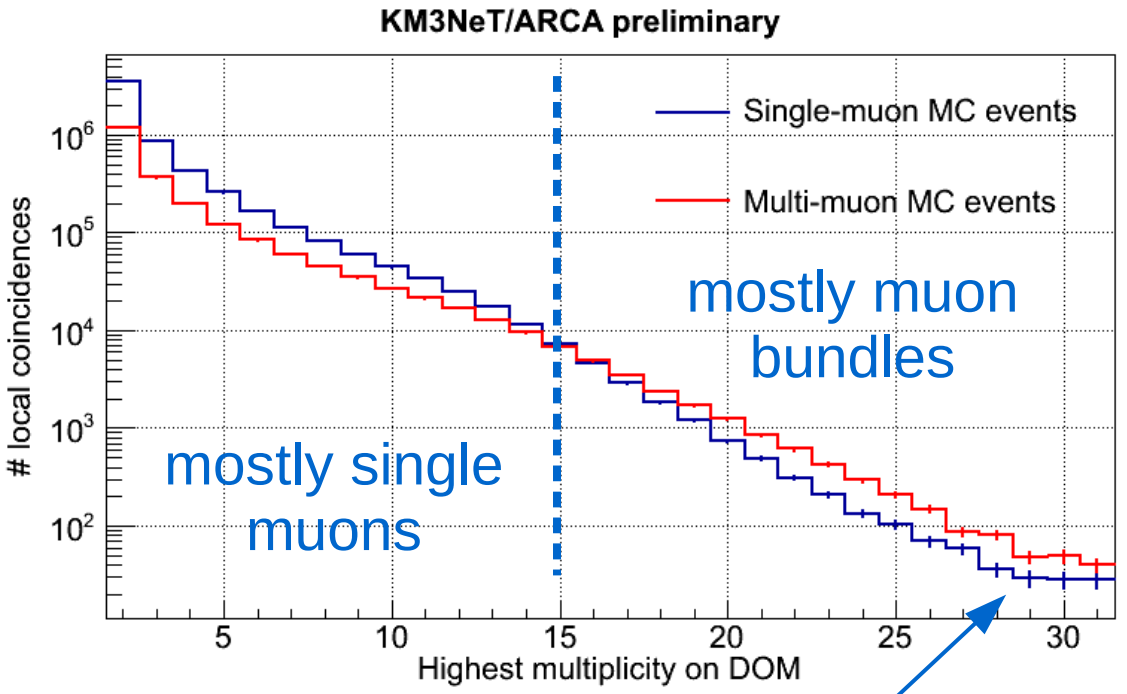
median E_μ 700 GeV

median E_μ 300 GeV

- Single muon MC events
- Muon energy increases with multiplicity

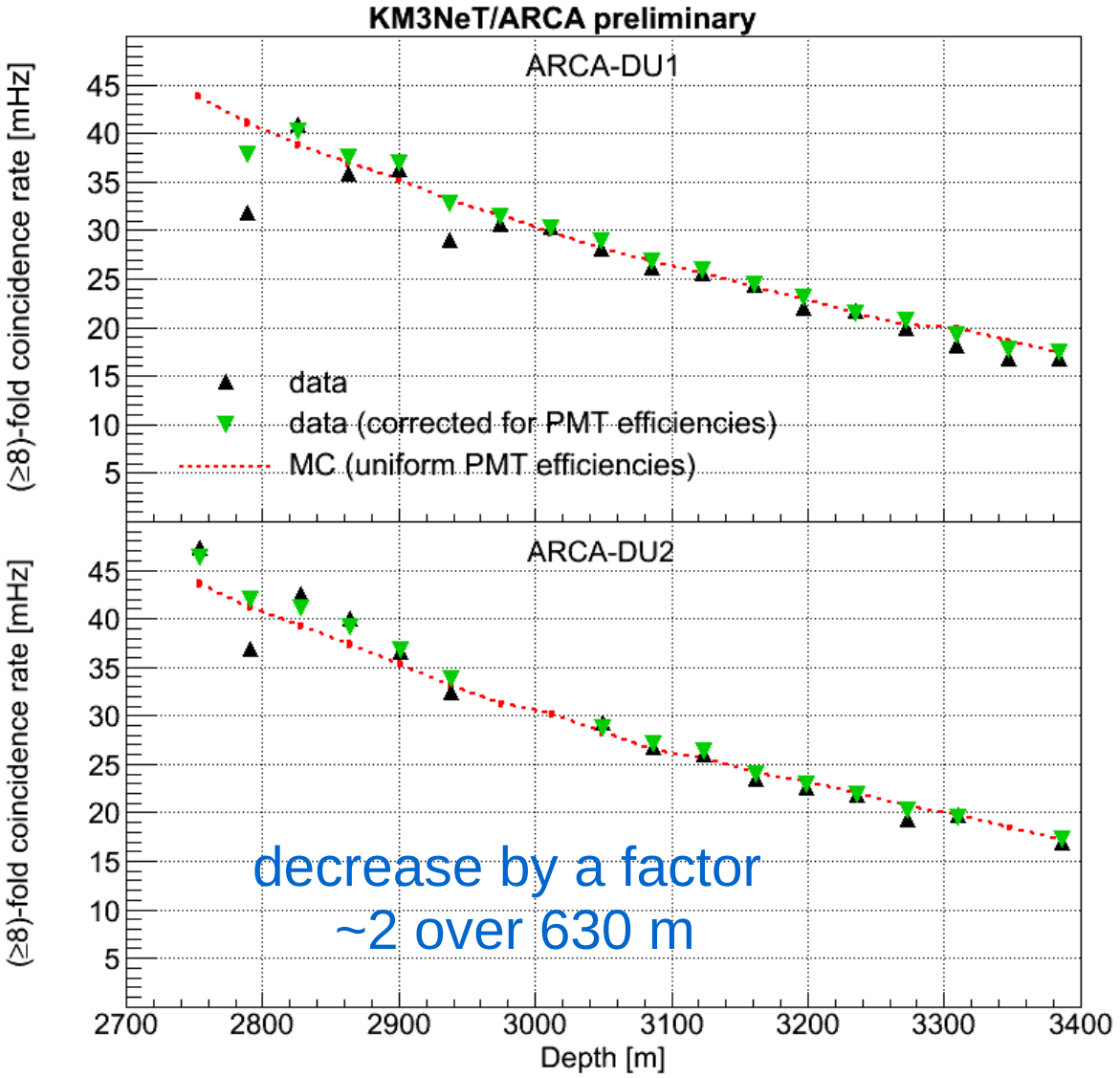
Muon bundle contribution

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



single-muon contribution significant even at extremely high multiplicities

Data/MC comparison



- Correction factor applied to each data point:

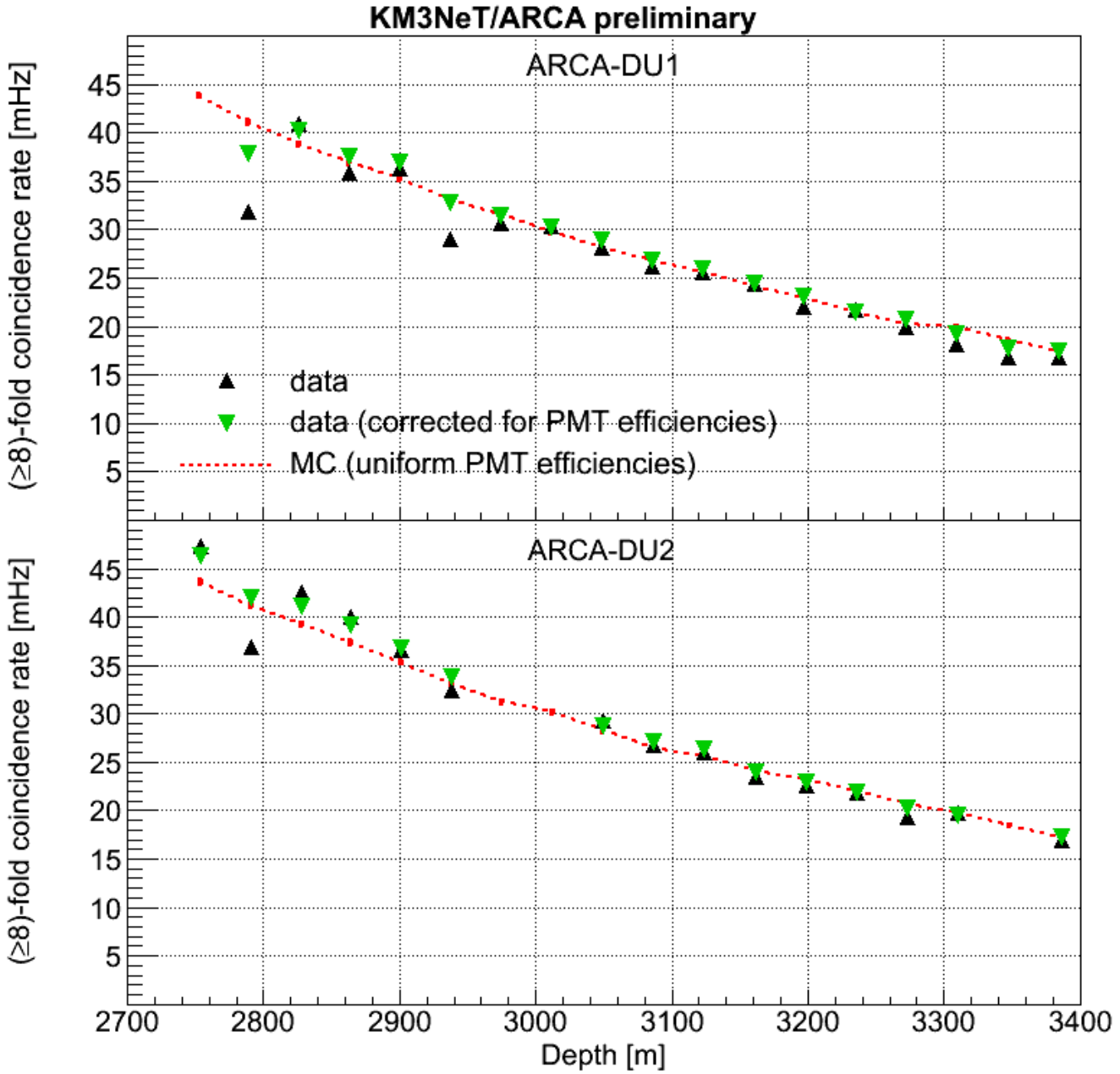
$$\frac{\text{MC rate (uniform efficiencies)}}{\text{MC rate (K-40 efficiencies)}}$$

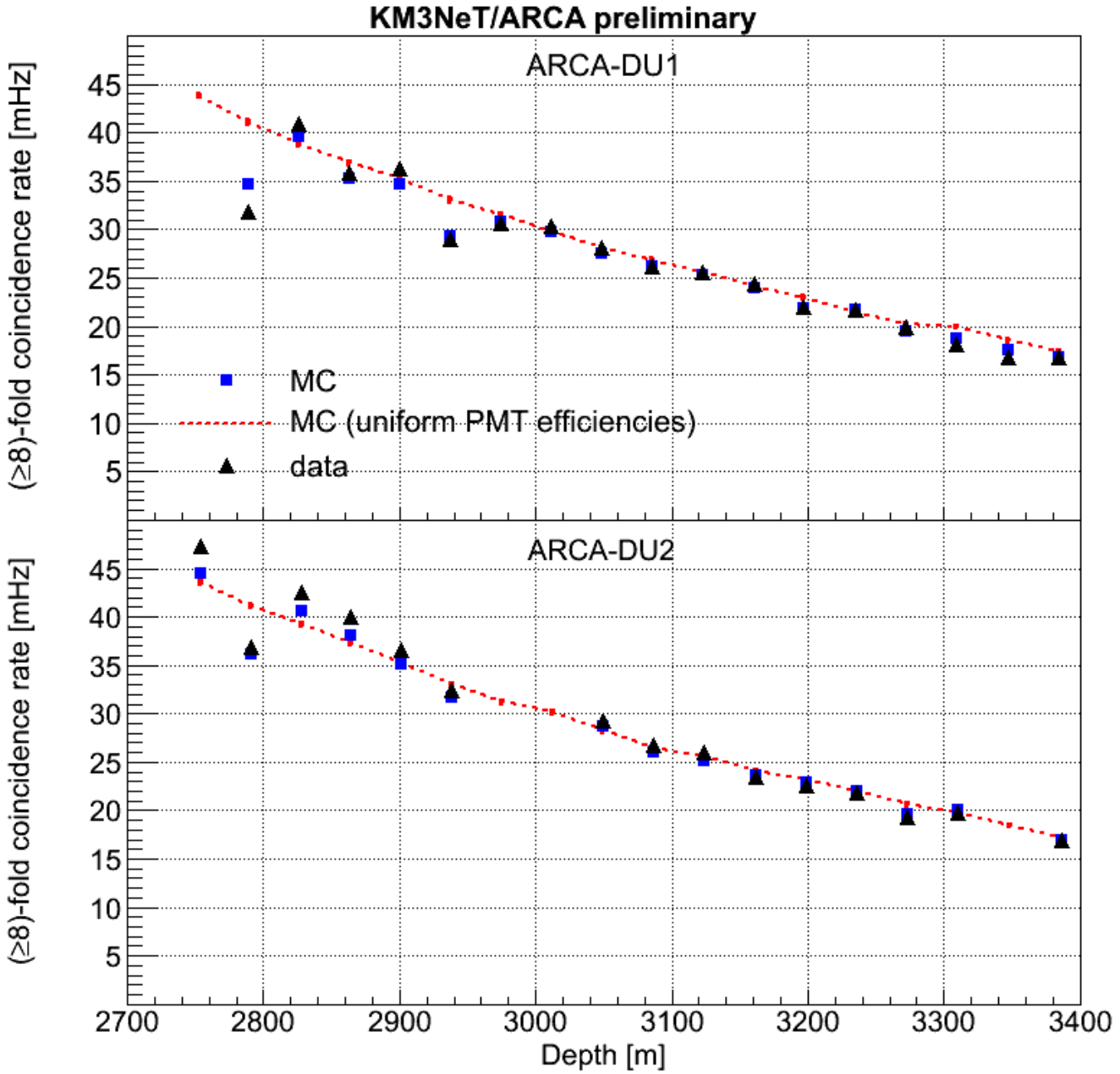
- Efficiencies from in-situ calibration improve data/MC agreement

Conclusions and outlook

- Depth dependence of high-multiplicity coincidence rates measured
  - ≥8-fold rates decrease by a factor ~2 along the 630 m depth difference
  - Excellent data/MC agreement
- First demonstration that K-40 PMT efficiencies improve data/MC agreement
- Atmospheric muon signal characteristics for m≥8 studied in MC
  - median energy 300-400 GeV
  - mostly single-muon events
  - 90% have distance of closest approach ≤20 m
- Outlook
  - compare different atmospheric muon generators (CORSIKA)
  - investigation of systematics
  - translate to measurement of physical atmospheric muon flux

Backup slides


KM3NeT/ARCA preliminary
ARCA-DU1
ARCA-DU2
data
data (corrected for PMT efficiencies)
MC (uniform PMT efficiencies)
(≥8)-fold coincidence rate [mHz]
Depth [m]
5
10
15
20
25
30
35
40
45
2700
2800
2900
3000
3100
3200
3300
3400


KM3NeT/ARCA preliminary
ARCA-DU1
ARCA-DU2
MC
MC (uniform PMT efficiencies)
data
(≥8)-fold coincidence rate [mHz]
Depth [m]
5
10
15
20
25
30
35
40
45
2700
2800
2900
3000
3100
3200
3300
3400