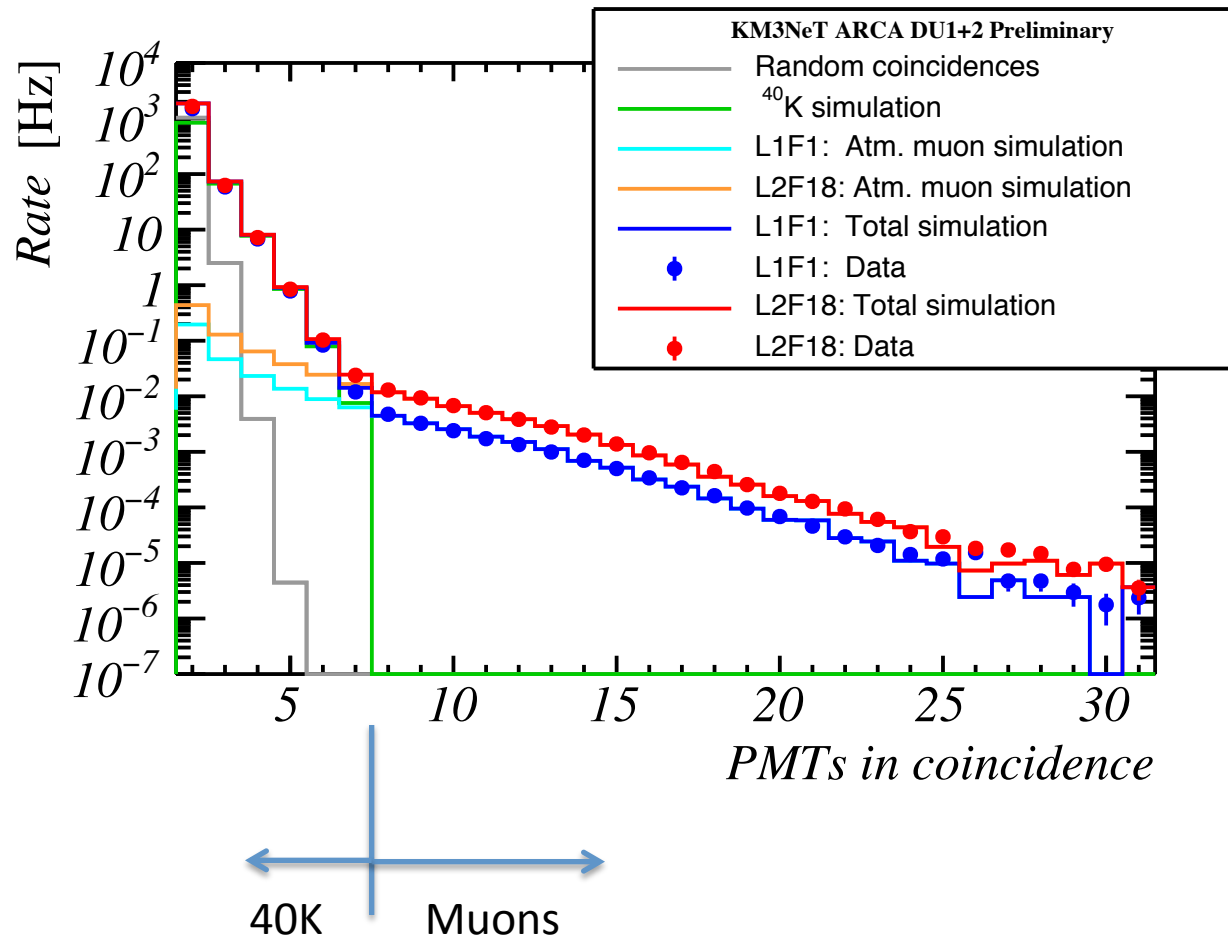


Muon Depth Dependence Paper

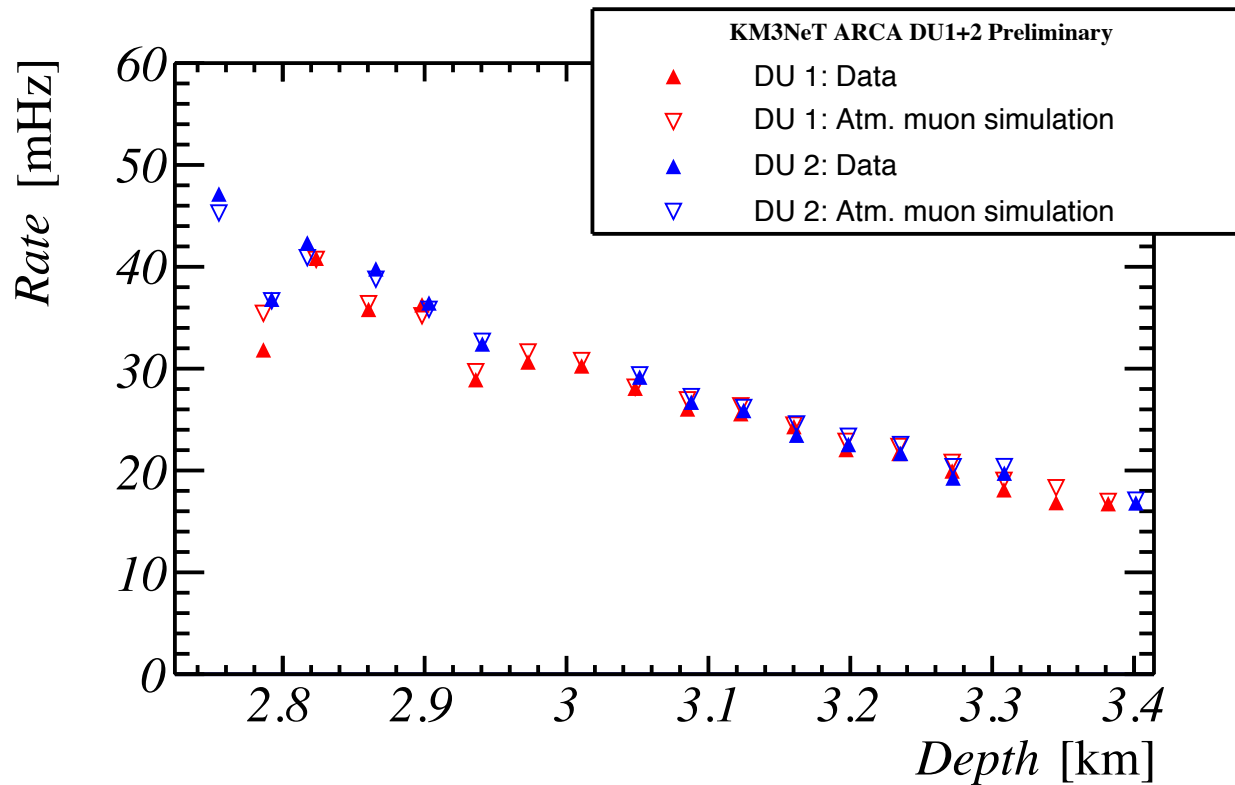
Historical Overview

- December 2015: First data
- Summer 2016: First depth dependence plots
 - Paul & Ronald: Should be in paper
 - Detailed MC (unofficial, rbr)
- December 2016: Politics and such
 - Official MC not compatible with data
- Summer 2017: ICRC presentation+proceedings

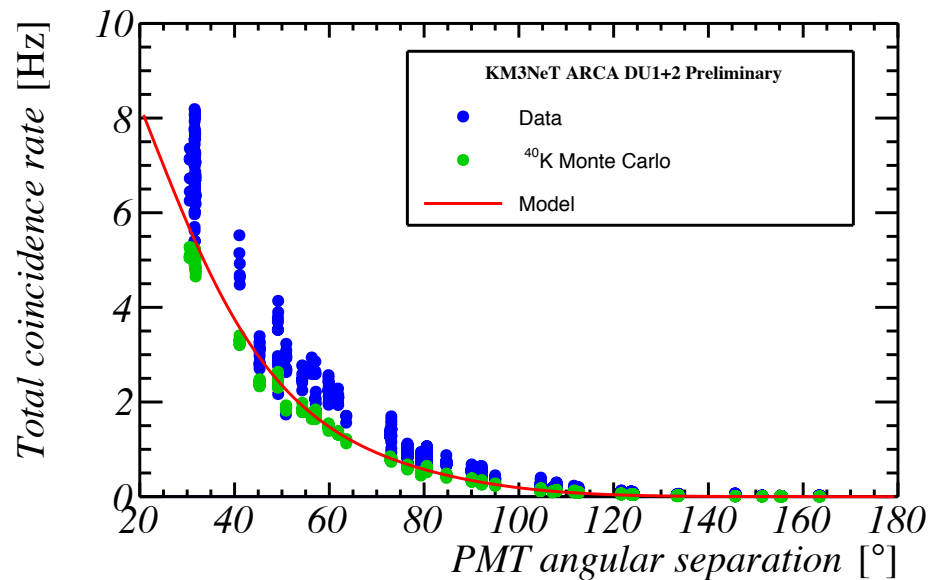
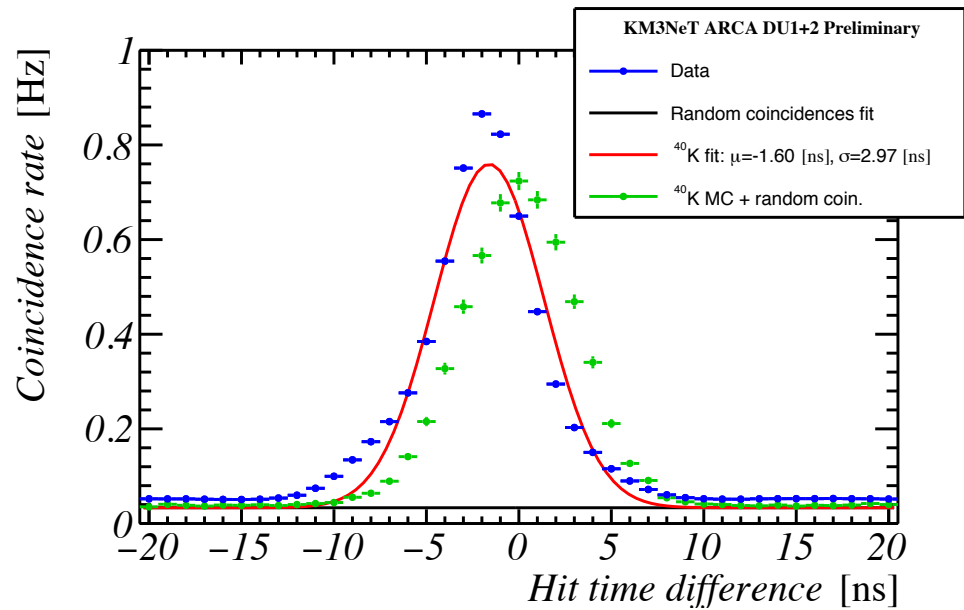
Muon Multiplicity



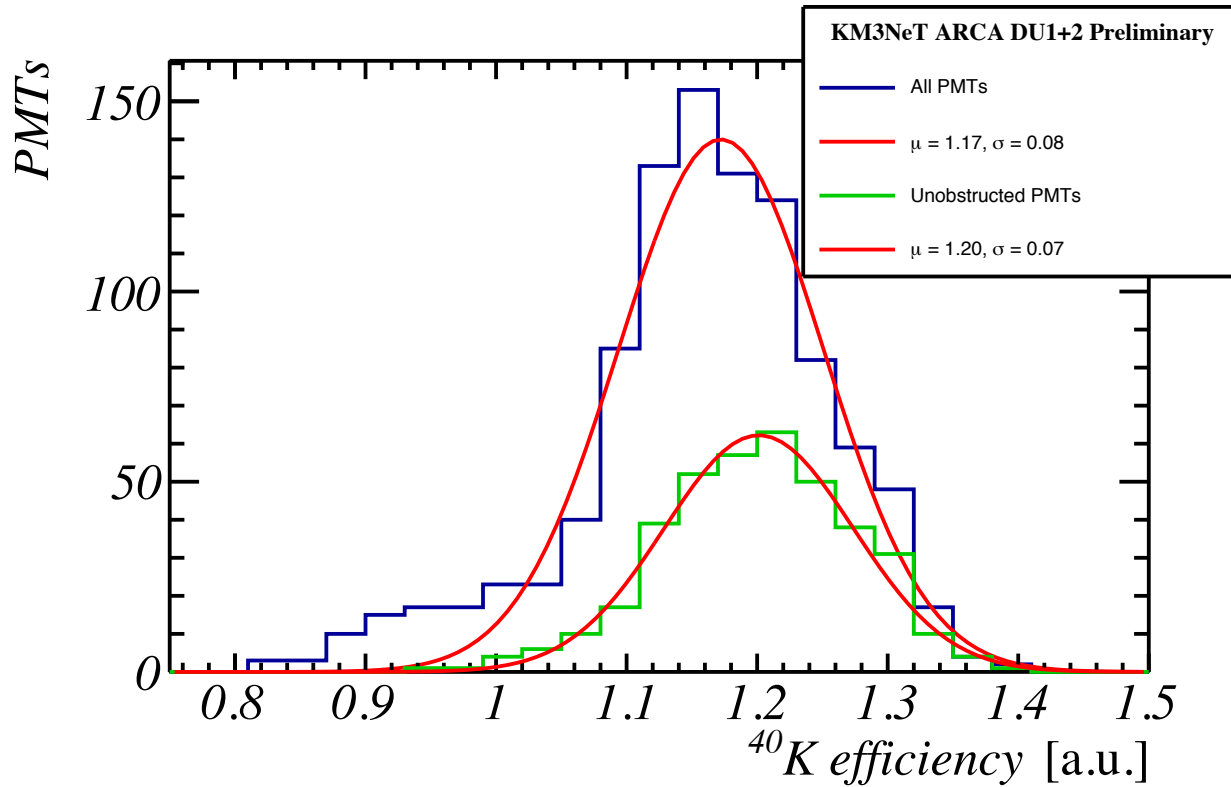
Muon Depth Dependence



Monte Carlo Simulations

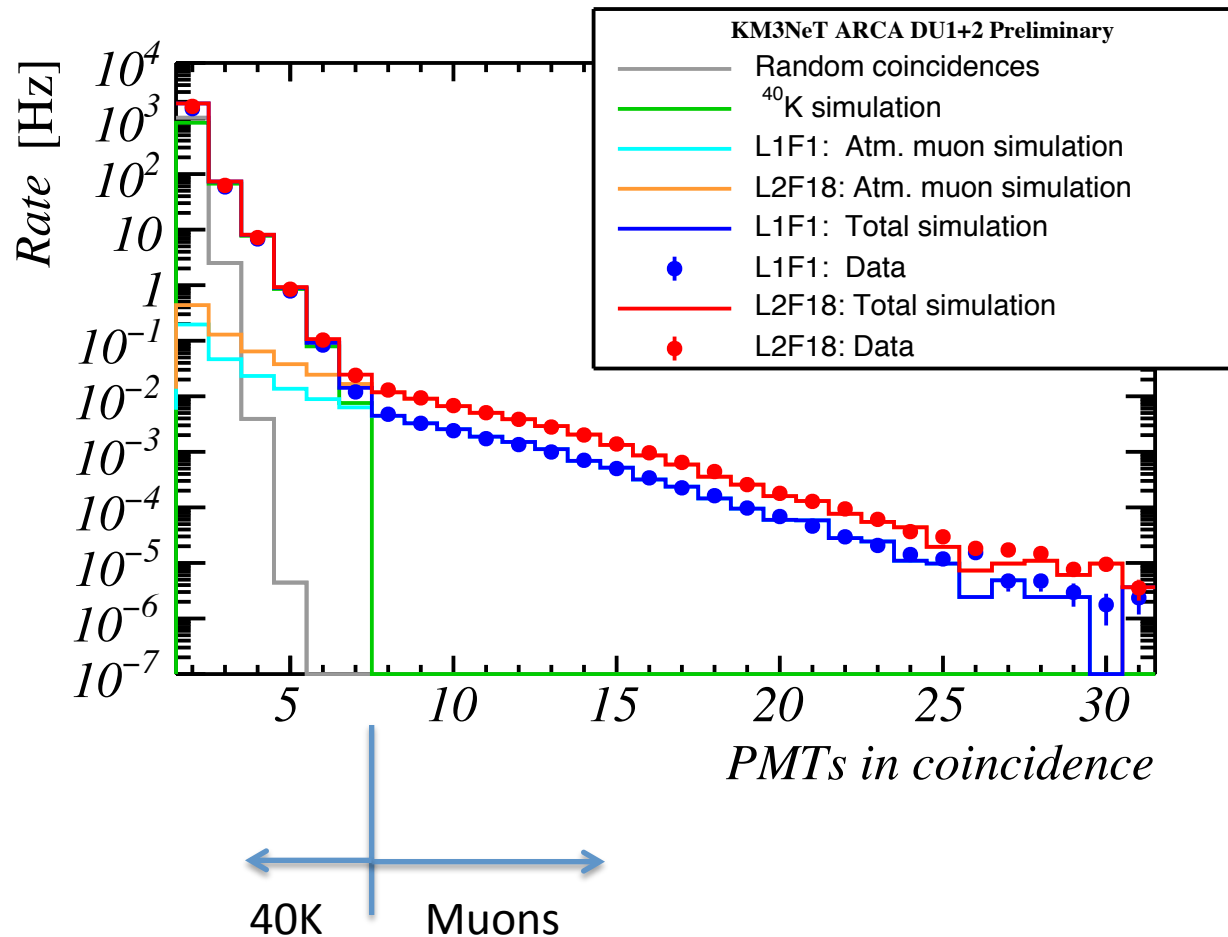


PMT efficiencies

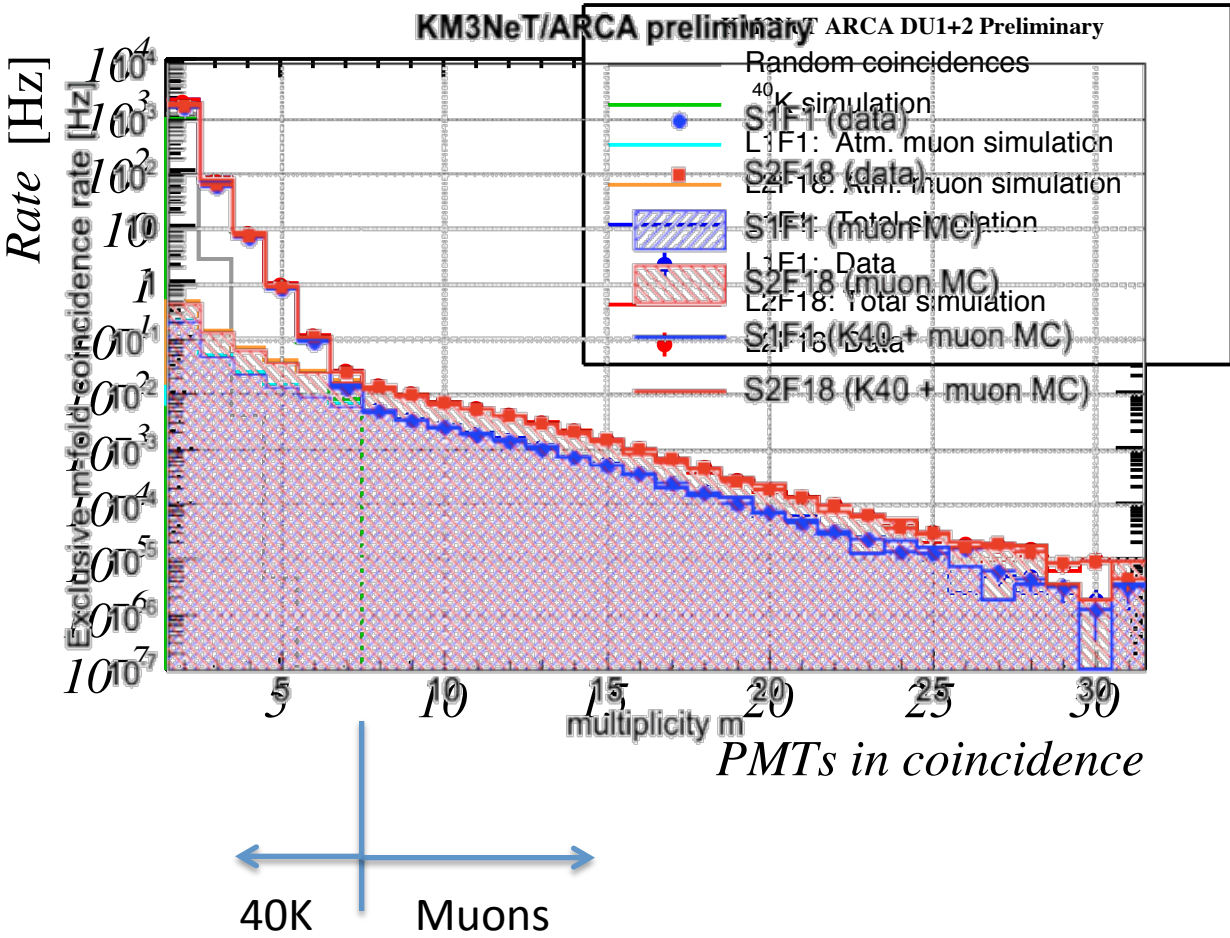


Checks with Martijn

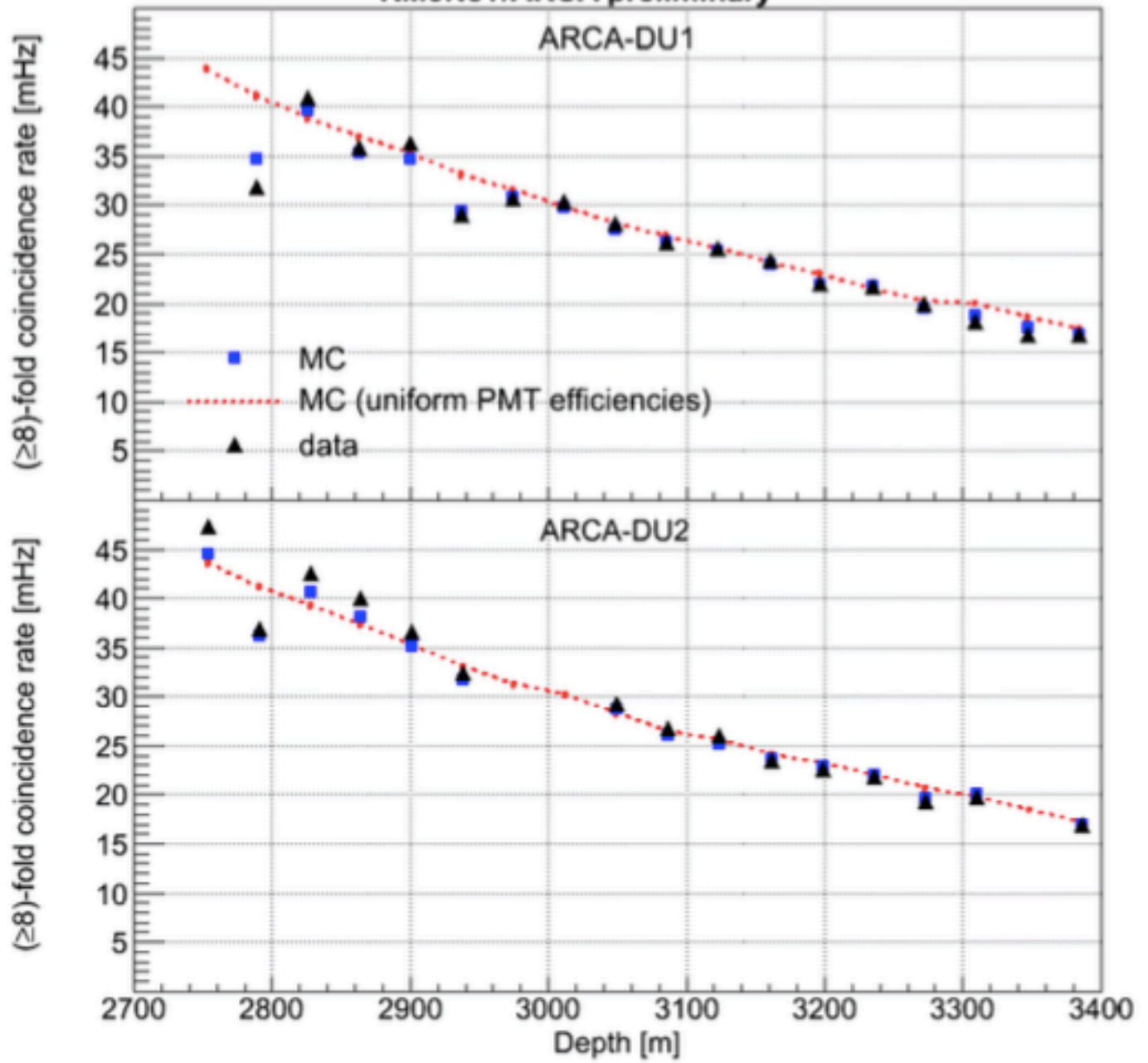
Muon Multiplicity



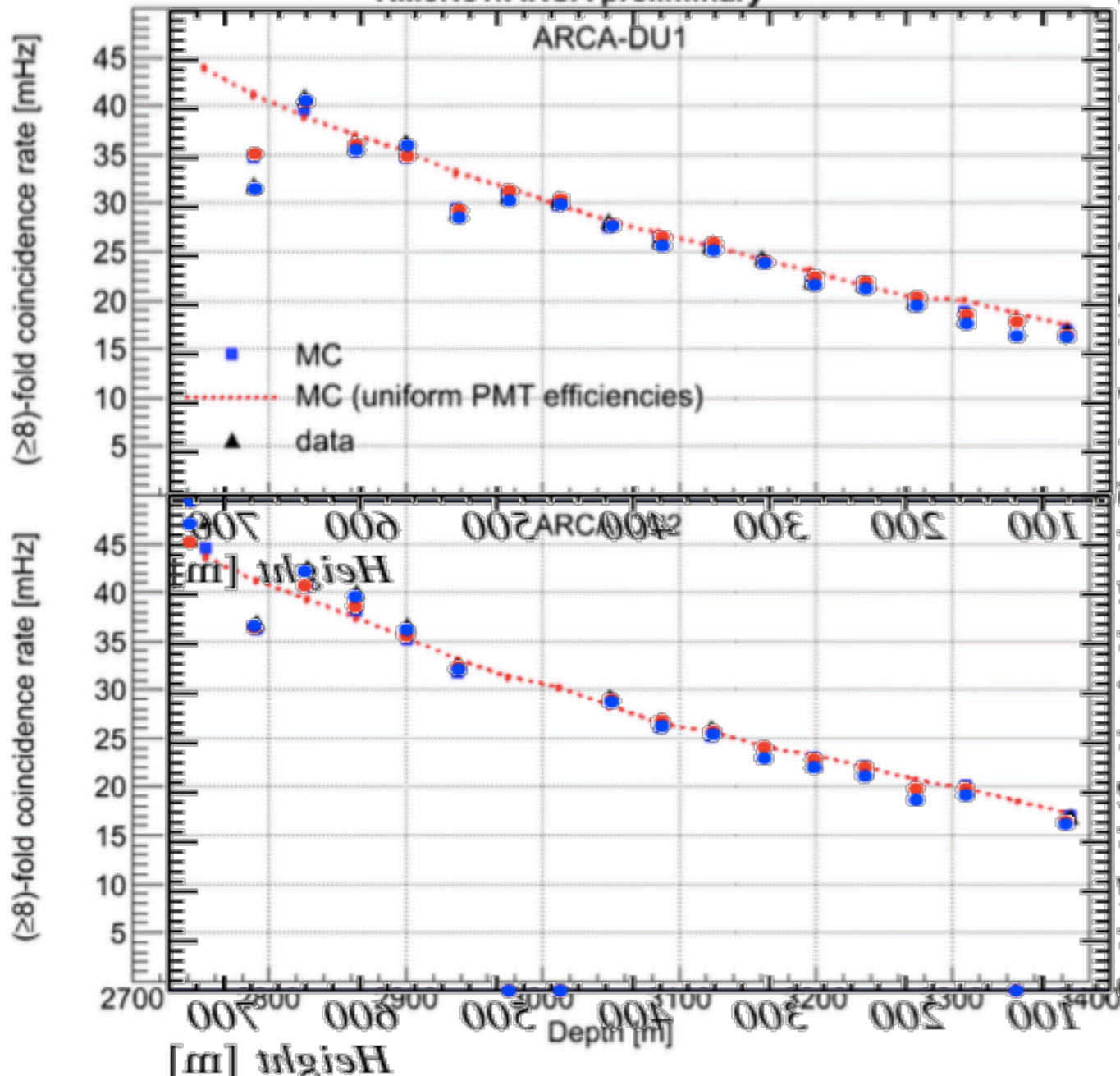
Muon Multiplicity



KM3NeT/ARCA preliminary



KM3NeT/ARCA preliminary



Outlook

- Include ORCA data
 - MC needed
- Some additional plots?
- Improve draft text

1 Introduction

The KM3NeT Collaboration is constructing an underwater neutrino research infrastructure in the deep Mediterranean Sea. The science objectives of KM3NeT is twofold: (1) the study of neutrino parameters, in particular the determination of the neutrino mass hierarchy with the KM3NeT/ORCA detector offshore Toulon, France and (2) the discovery and subsequent observation of high-energy neutrino sources in the Universe using the KM3NeT/ARCA detector offshore Capo Passaro, Italy. The construction of the KM3NeT ARCA (exp. ORCA) detector has started in December 2013 (December 2017) with the successful deployment of the first detector units.

In this paper, the practical understanding of our detector will be addressed by comparing results obtained from the first data with detailed Monte Carlo simulations. To this extent, data taken during a stable period from ... will be used.

2 The KM3NeT Detector

The key detection module of the KM3NeT neutrino telescope consists of a precision-machined glass sphere, housing 30 time-like Bicristalline PMTs with accompanying DRG electronic and calibration devices called a digital optical module (DOM) (ref. to some technical paper). In our modelled detector (see DOM), support DOMs are attached to the central spine, kept upright by a buoy and positioned on the outside using an anchor. Via a network of optical fibres and electrical cables, all DOMs are provided with electricity, while sending the data to shore for further analysis.

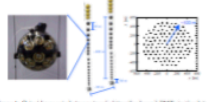


Figure 1: Connections seen between two (arbitrarily chosen) PMTs to the data.

A building block module of 100 DOMs. The vertical and horizontal spacing of the DOMs is optimized for the objective of the building block, a KM3NeT/ARCA (exp. KM3NeT/ORCA) building block, the DOMs are approximately 30 (30) metres apart with a 300 (30) metre total

metal spacing between the DOMs.

The occurrence of 0-4 PMTs in a DOM are digitized with a threshold technique as described in (ref. to some technical paper [ref]). The list of DOMs are used to the shore station, where the transmission is acquired and multiple trigger algorithms with cut-off digital events. A dedicated software focuses on collection and monitoring of the data. In this document, all listed coincidences of line within 20 microseconds on each DOM are written. For the results obtained in this paper, the dataset is used.

3 Inter-PMT Calibration

The light produced in the reflective design of PMTs is used to calibrate the relative PMT efficiencies and time offsets of the PMTs within a DOM. The method used is described in detail in [ref. to some technical paper [ref]]. In Figure 2, the distribution of the fitted relative PMT efficiencies is shown. As can be seen, the mean PMT efficiency is 17% larger than nominal, indicating that the PMTs are using more light than reported from detailed GEANT4 simulations. A second population of PMTs towards lower efficiencies can be observed. These PMTs are all related close to the DOM support structure. All PMTs close to any support structure are excluded to the given distribution, as can be seen, the resulting PMT efficiencies are Gaussian distributed with a mean (sigma) of 1.06 (0.07).

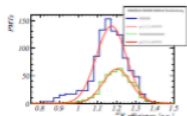


Figure 2: Distribution of fitted PMT efficiencies, obtained from ¹²C measurements. The line distribution includes all PMTs, the grey distribution only PMTs constructed by the nominal DOM support structure.

stability?

4 Monte-Carlo Simulations

Stability? PMT gain and geometry, slight noise?

Apart from the detailed GEANT4 simulation of ¹²C events, a set of Monte-Carlo simulated atmospheric muon events has been obtained. The flux of atmospheric muons is simulated using the best energy parameterization [ref], followed by the simulation and propagation of the produced Cherenkov photons with the best package [ref].

The detector response has been simulated using the internal KM3NeT application (Zhang et al. 2016). The per-pair and per-event, relative efficiencies obtained from the ¹²C fit procedure and further are taken into account in a study-to-study basis.

5 Coincidences and Muon Depth Dependence

Includes stability?

The distribution of the number of PMTs in a DOM continuously registering a hit is shown in Figure 3. A coincidence of *N* PMTs is defined as a sequence of hits on *N* unique PMTs within a time window of 20 microseconds from the first hit.

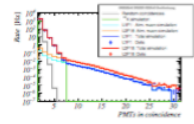


Figure 3: Distribution of number of unique PMTs in a coincidence. The distribution of DOMs 1-27 (0-2.4 kilometers below seafloor) and 28-30 (0-2.7 kilometers below seafloor) are plotted in blue and red respectively.

Consider up to 4 PMTs are described by function coincidences of coincident hits and correlated hits from ¹²C depths. All coincidences as less 4 PMTs are not described by the fit due of atmospheric muons. As can be seen, the coincidence of both parameters are in excellent agreement

with the observed data over 8 months of registration.

With the rate of ¹²C decays is constant along the line, the number of muon decays will slightly drop due to the energy loss of muons in the water. In Figure 3, this is apparent from the comparison between the distribution of DOMs 1-27 at a depth of 2.4 kilometers and 28-30 at a depth of 2.7 meters. The integrated 1-4 hit coincidences rate of all active DOMs is plotted in Figure 4.

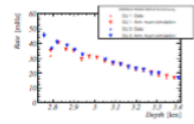


Figure 4: Integrated 1-4 hit coincidences rate of all DOMs as function of depth below the seafloor.

The expected trend of the expected number of muons is clearly visible in this line. Variations due to the difference in the PMT efficiencies of the DOMs are well described by the response atmospheric muon simulation.

6 Conclusions

First activities have successfully deployed and work as expected. Practical understanding of our detector is well first measurement of the muon flux in an deep-sea neutrino observatory?

References

S. Adrià-Negre et al. (The KM3NeT Collaboration), Letter of Intent for KM3NeT 2.0, arXiv:1601.04696, 2016.

S.W. Hahn on behalf of the KM3NeT Collaboration, In-Situ Calibration of KM3NeT. In: PUBLIC/2017/01/01, 2017.

