University of Amsterdam
Institute of Physics

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KM3NeT

KM3NeT calibration overview

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on behalf of the KM3NeT collaboration

Calibration goals

Positions (<20cm)

→ acoustic emitters / receivers

Orientations

→ compass / tiltmeter

Timing (nanoseconds)

→ Synchronization (White Rabbit)
→ Light from nanobeacons / laser
→ Light from potassium (^{40}K) decay
→ Light from muons

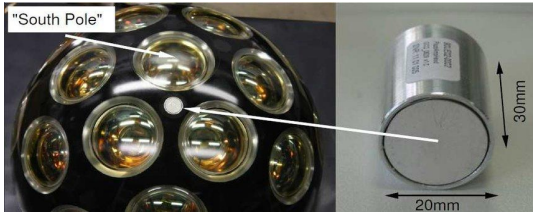
Efficiency / Gain / Angular acceptance

→ Efficiency from light yield from potassium (^{40}K) decays
→ Gain determination from **T**ime **o**ver **T**hreshold (ToT) distributions
→ Angular acceptance via dark room measurements, ^{40K}K, muons

Water properties (scattering/absorption)

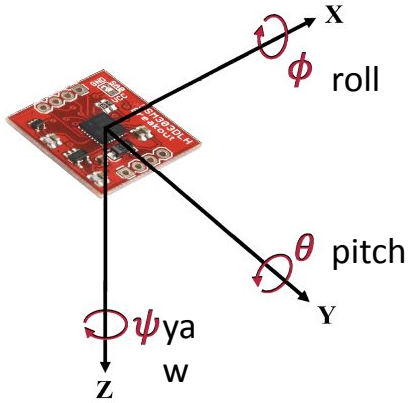
→ Light from muons
(→ dedicated light source?)

Calibration devices



Piezo
sensor
on DOM

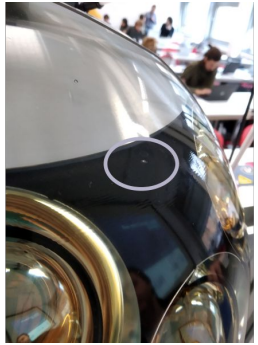
Compass chip
Board mounted
on Central
Logic Board in
DOM



Hydrophone
on string
bases

Acoustic Beacon
an (some) string bases,
(also autonomous
ones)

Nanobeacon
(LED) on DOM
Wavelength
470nm

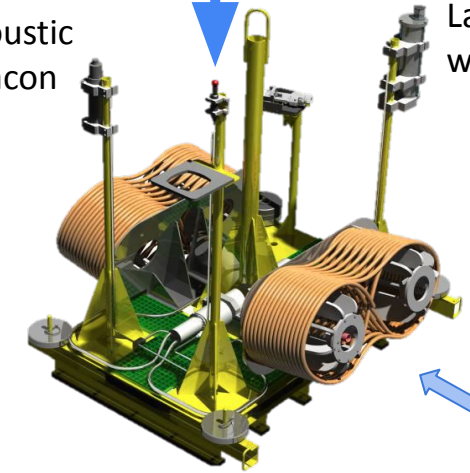


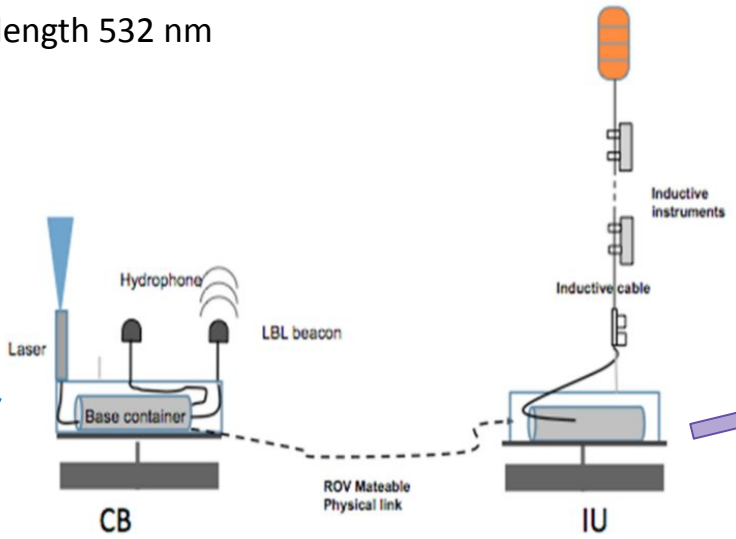
Calibration units

Hydrophone

Acoustic Beacon

Laser beacon wavelength 532 nm



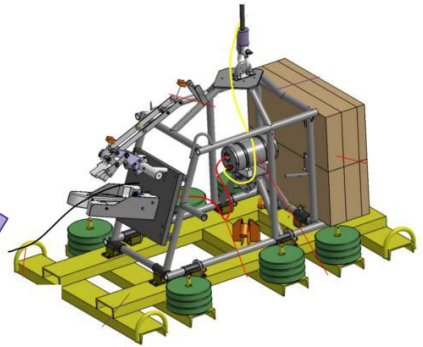


Calibration Base

Instrumentation Unit

Instrumentation Unit measuring:

- Conductivity
- Pressure
- Temperature
- Salinity
- Current



Acoustic systems

Acoustic emitters

- Autonomous acoustic beacons (around the string arrays)
- Triggered acoustic beacons (on some string bases and on Junction Boxes and on Calibration Unit)

Each beacon uses a characteristic emission pattern (frequency, waveform) 20-40kHz range

Acoustic receivers

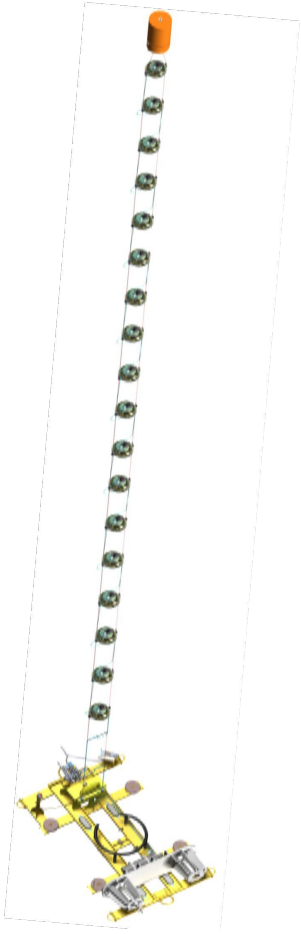
- piezos (in all DOMs)
  → *moving with DOMs*
- hydrophones (on the base of each string, Junction Boxes and Calibration Unit)
  → *fixed on Seafloor*
  → *high dynamic range, to be used also for Sea sciences (whale monitoring)*

During data taking online filtering of receiver signals to identify emitter patterns

→ Recording 'time of arrival' and 'quality' for all beacon signatures, frequency ~10minutes
=> Position determination in minimizing differences of expected to measured times
=> multidimensional problem (constraining emitter/receiver positions, emission times)

→ Regularly also taking raw data (with selected receivers) for Sea Science evaluations (Whales, …)

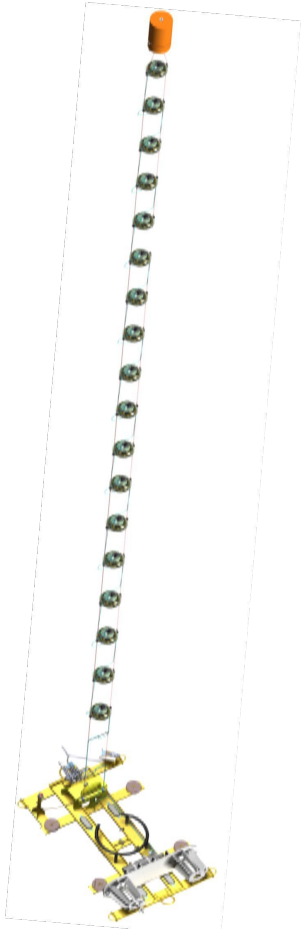
String tilts



What tilts more in the horizontal direction:

ORCA-string or tower of PISA?

String tilts

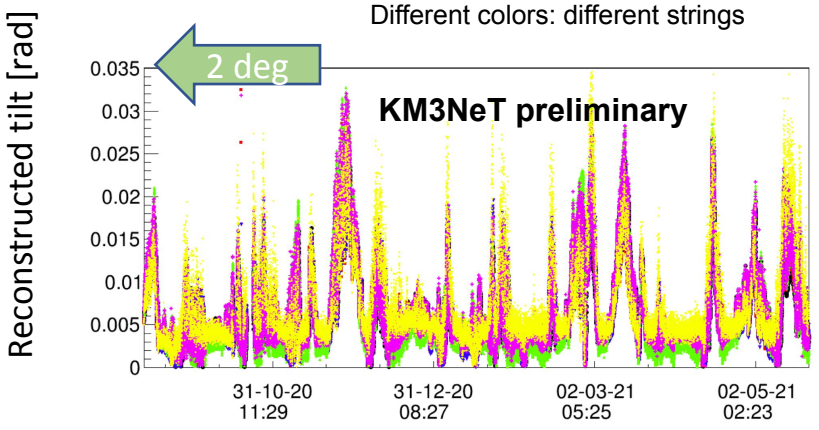


What tilts more in the horizontal direction:

PISA tower

Wikipedia:
Height of Pisa tower is 55.86 metres.
By 1990, tilt had reached 5.5 degrees.
Structure was stabilized by remedial work between 1993 and 2001, which reduced tilt to 3.97 degrees.

KM3NeTpedia:
Height of ORCA string is 190 metres.
Structure is stabilized by buoyancy of glass spheres.
In 2020/21, tilt was less than 2 degrees



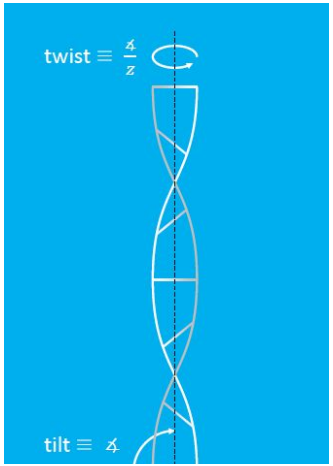
Orientation calibration

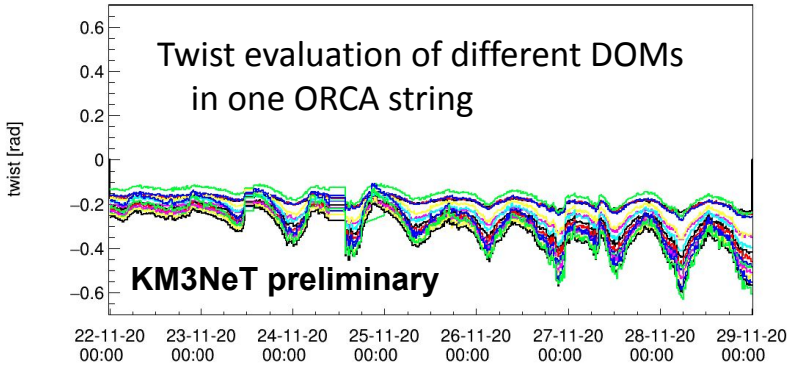
Compass chip on CLB of the DOM provides orientation information (yaw, pitch, roll)

Calibration of intrinsic offsets using the naked CLB before DOM integration

In-situ calibration of remaining offsets

Orientation description via quaternions:
Tilt & Twist





Time calibration

- **Synchronization at nanosecond precision via White Rabbit technology**
  White Rabbit: Development partners from industry & universities, CERN
  Ethernetbased network, subnanosecond synchronization
  → Referenced to GPS clock

=> Talk Diego Real

- **Time offsets have to be accounted for on different levels:**

Intra-DOM time offsets (between PMTs on a DOM)
→ determination via light signals from ^{40}K decays

Inter-DOM time offsets (between DOMs on a string)
→ determination via light signals from (laser) / nanobeacons / muons

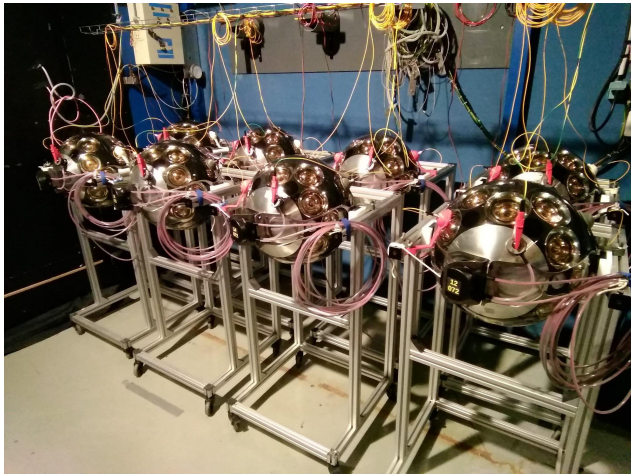
Inter-DU time offsets (between DUs)
→ direct measurements of Round trip time
→.determination via light signals from lasers / muons

Inter-DOM time calibration

In the dark room a laser signal is routed via a splitter to each DOM
→ light signals used for DOM time offsets

In-situ the nanobeacons of the DOMs can be flashed (in staggered way)
→ DOMs above flashing one measure correlated signals
→ distance to DOMs known determination of relative time offset

Dark room measurement
Setup at CPPM, Marseille



Inter-DOM time calibration

In the dark room a laser signal is routed via a splitter to each DOM
→ peaks provide DOM time offsets

In-situ the nanobeacons of the DOMs can be flashed (in staggered way)
→ DOMs above flashing one measure correlated signals
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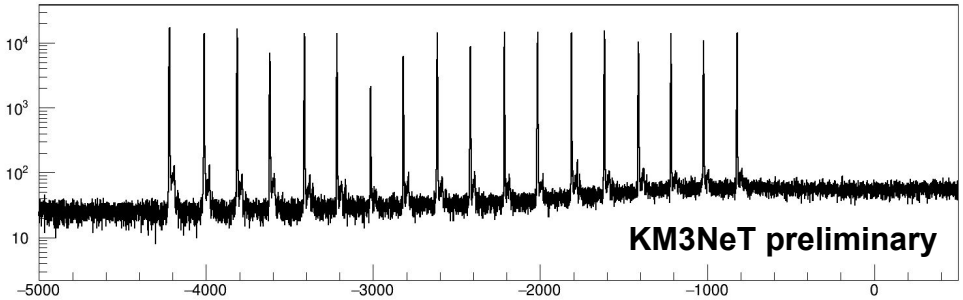
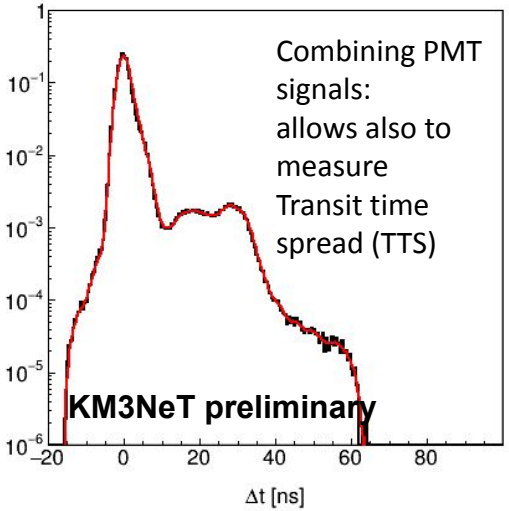
Dark room measurement





Important for simulating time resolution

Inter-DU time calibration

Muon calibration

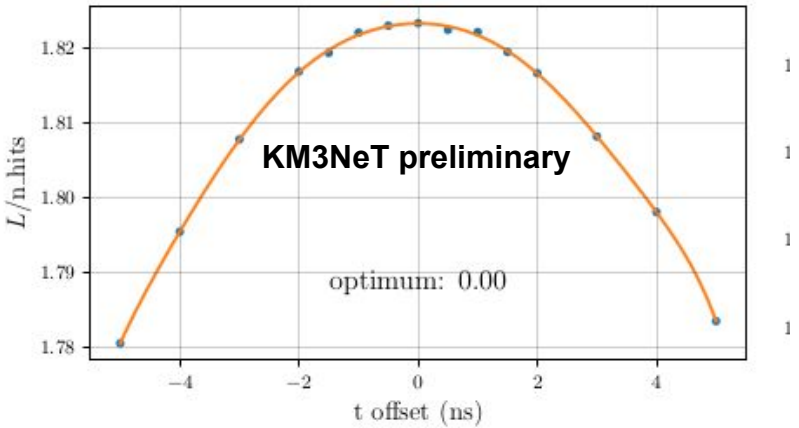
1) Reconstruct muon tracks
2) Maximize quality

→ inter-DU timing
(also possible inter-DOM time offsets, positions, rotations)

Position agreement with acoustic positioning in ORCA **<10cm**

Rotation agreement with orientation From compass information **<deg**

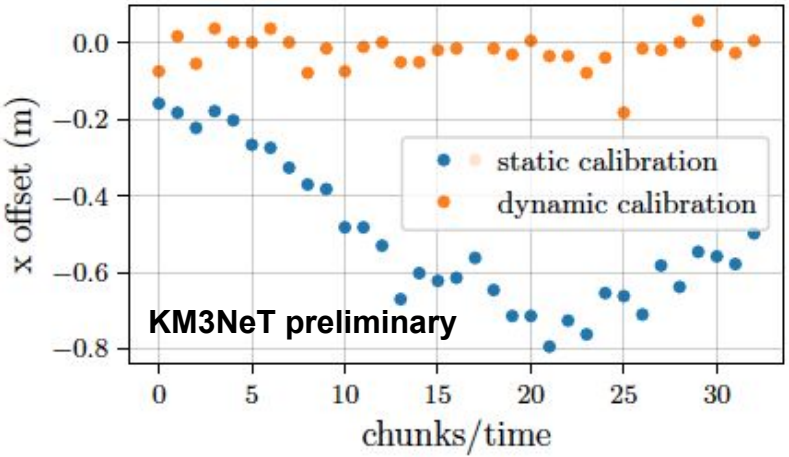
ORCA data (for one string)

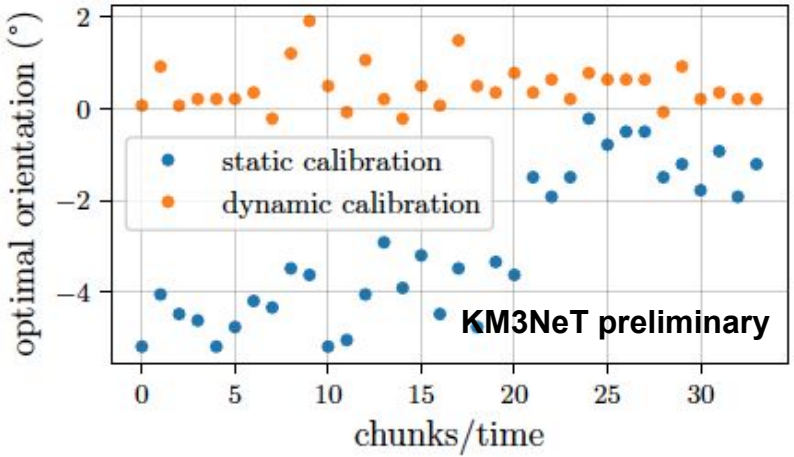


Muon calibration cross-checks

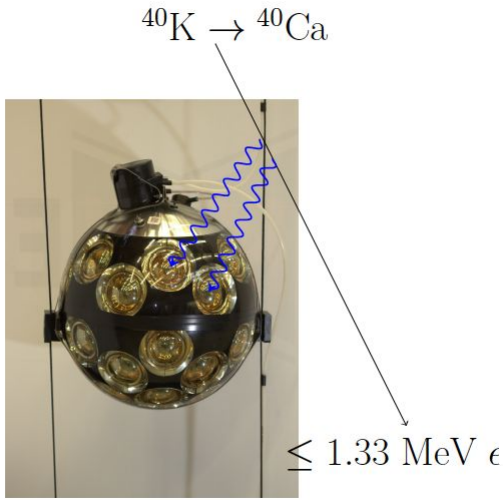
Dynamic (time-dependent) position/orientation calibration confirmed with muon calibration

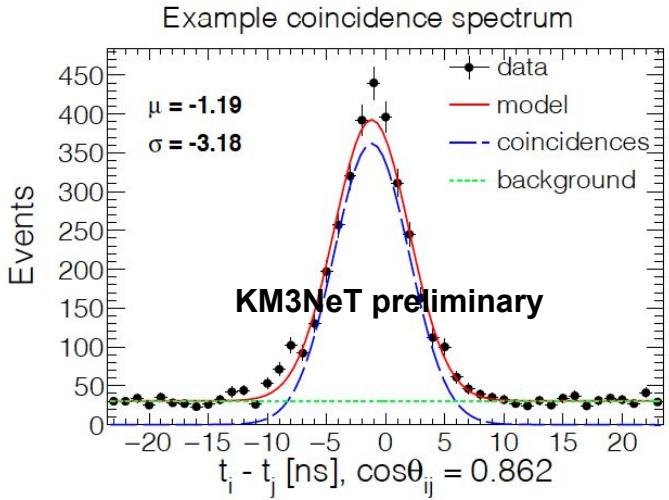
ORCA data

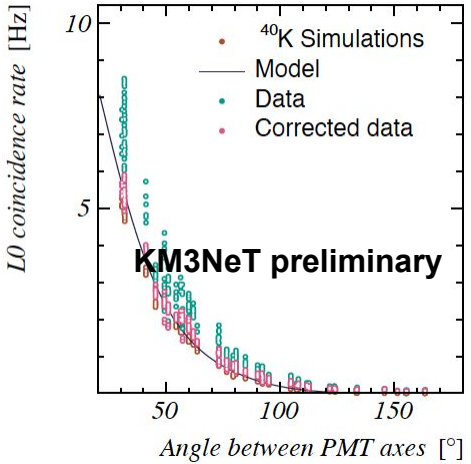




Intra-DOM time & efficiency calibration





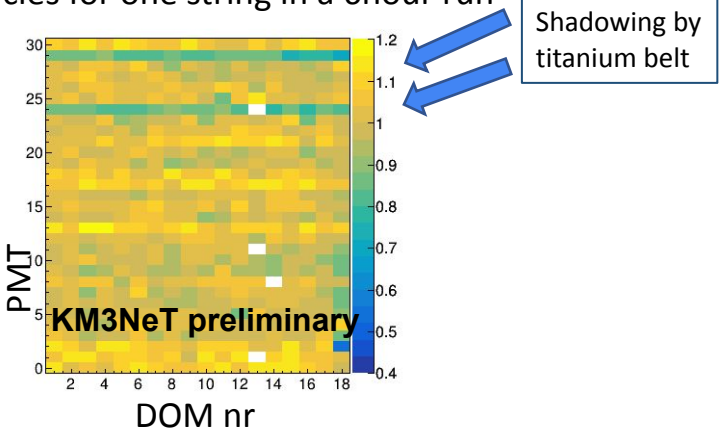


Mean: Time offset difference
Width: Transit Time Spread (+intrinsic ^{40}K spread ~0.5ns)
Integral: Combined efficiency (distance dependent)

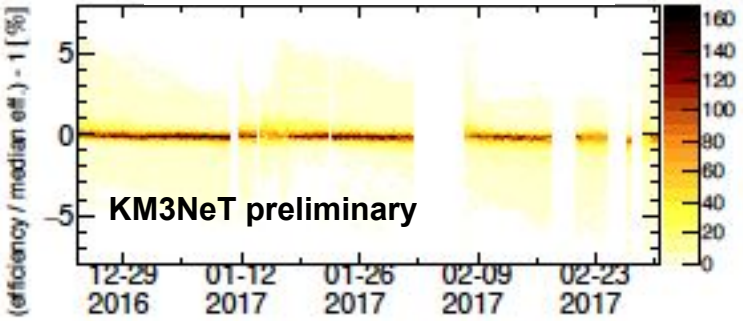
Global fit of distributions for all 465 PMT pairs of a DOM
=> for each PMT time offset & efficiency

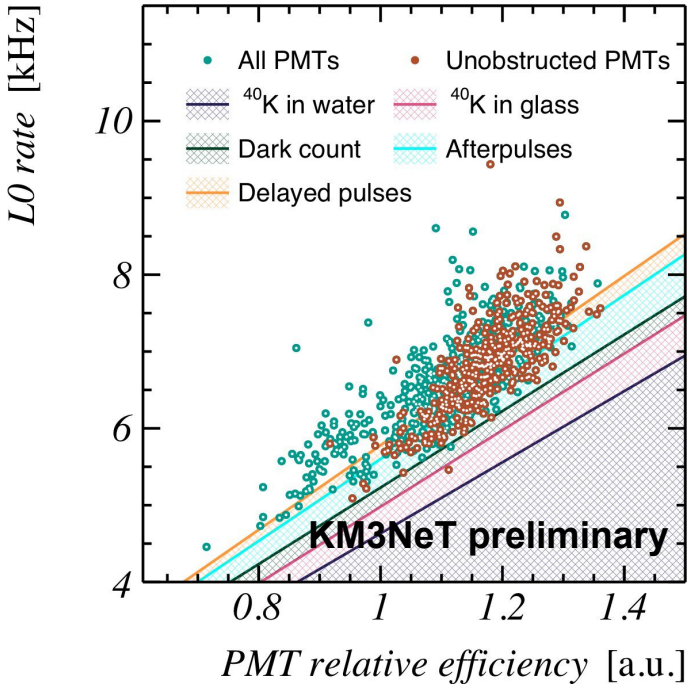
PMT efficiencies

Efficiencies for one string in a 6hour run



Relative efficiencies as function of time





Single rates in the Sea correlate well with determined efficiencies

Moon / Sun shadows

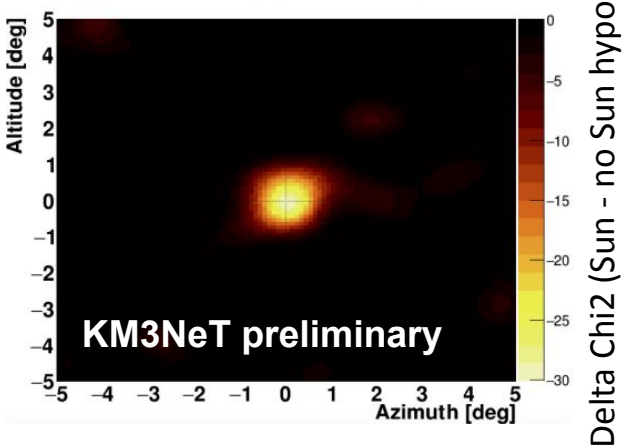
No calibration source available for pointing confirmation

=> Use '***anti-signal***' in muons:

Cosmic rays are blocked by Moon/Sun

⟶ check for 'hole' in atmospheric muon density in direction of Moon/Sun

Evaluation of 1 year ORCA-6 data
Sun Shadow



Confirmation of detector positioning, timing and muon track reconstruction

Summary

Dedicated calibration systems set up for:

- Positioning
- Orientation calibration
- Timing calibration
- Gain and efficiency calibrations

Working and applied in darkrooms and sea right now

Thank you

Questions?