In-situ calibration of KM3NeT PMTs with K40

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Outline

1. Introduction
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6. Summary
KM3NeT - large volume neutrino telescopes at the bottom of the Mediterranean.

- **ARCA** - high energy $\nu$ astronomy.
- **ORCA** - oscillation research with atm. $\nu$. 
Figure: Illustration of $\nu$ detection in KM3NeT.
ν-detection is based on Cherenkov light collection.

Reco @ Multi-PMT DOM level
- Cherenkov direction → angle resolution.
- Hit multiplicity → energy resolution.

Reco @ PMT level
- Accurate hit time → angle resolution.
- Time-over-threshold (ToT) → energy resolution.
K40 decay signal

$^{40}\text{K} \rightarrow ^{40}\text{Ca}$

K40 naturally present in sea water.

Isotropic signal from decays.

2-8 PMTs hit in coincidence.

→ use coincidences for calibration.
Time calibration

31 PMTs $\rightarrow 31 \times 30/2 = 465$ pairs per DOM.

- Fit to extract $\mu_{ij} = t_i - t_j$, $i \in [1, 31], i \neq j$
- Find offsets $\Delta t_i$ for $i \in [2, 31]$, such that $\mu_{ij} \sim 0$.
- Find widths $\sigma_{ij}$ (K40 intrinsic $(0.54) +$ TTS).

Figure: Coincidence spectrum of a PMT pair, $\theta = 30.45^\circ$
Time calibration

Time offsets $\Delta t_i$ can be used:

- for updating the calibration of the detector in the sea.
- as input to Monte-Carlo to match it to data.

Width $\sigma_{ij}$ can be used:

- as input to Monte-Carlo to match it to data.

→ Timing calibration in the order of 1 ns!
PMT efficiency

- Subtract background from coincidence spectrum.
- Divide by run time.

Coincidence rate $R$ per each PMT pair $\rightarrow$ plot $R$ vs pair opening angle $\theta$. 
31 PMTs $\rightarrow 31 \times 30/2 = 465$ pairs per DOM.

- Extract rate $R_{ij}, i \in [1, 31], i \neq j$
- Find $c_i, c_j$, such that $c_i c_j R_{ij} \simeq Model(\cos\theta_{ij})$

$c_i$ are PMT relative efficiencies.
PMT efficiency

Relative efficiencies $c_i$ can be used:

- To match Monte Carlo to data.
- As guidance for PMT high-voltage tuning.

Input to $c_i$ determination:

- K40 abundance in sea water.
- Detector geometry in simulation.

Cross-checks:

- Nanobeacons $\rightarrow$ time cal.
- Atm. muons $\rightarrow$ eff. cal.
K40 calibrations have been successfully used in ANATRES for \( \sim 10 \) years.

ANTARES three-DOM floor.

ANTARES \( \Delta t_i \) and \( c_i \).
K40 decays can be used for accurate time calibration.
K40 decays provide info about PMT relative efficiencies.
K40 calibrations can be cross checked against other analyses.
Has been successfully used in ANTARES.

Thank you for your attention!
Figures from:

1. www.km3net.org
2. Letter of Intent for KM3NeT 2.0
4. M. Jongen nanobeacon analysis.
5. Long-term monitoring of the ANTARES optical module efficiencies using 40K decays in sea water