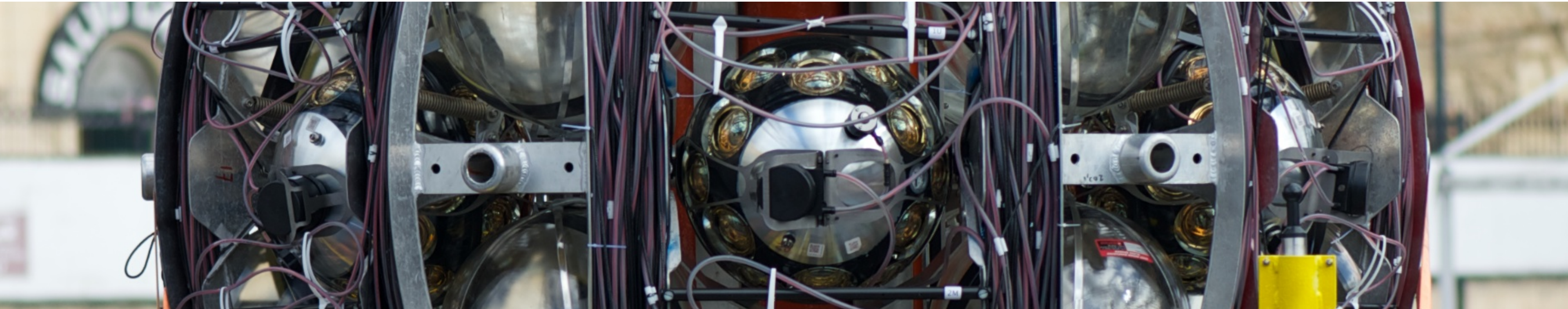
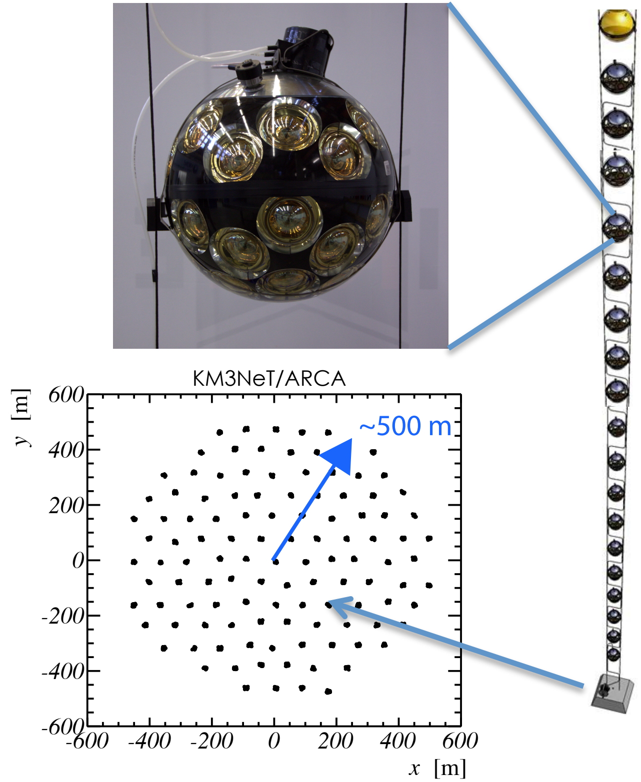
KM3NeT Calibration

Karel Melis

Nikhef Jamboree (2017) – Amsterdam



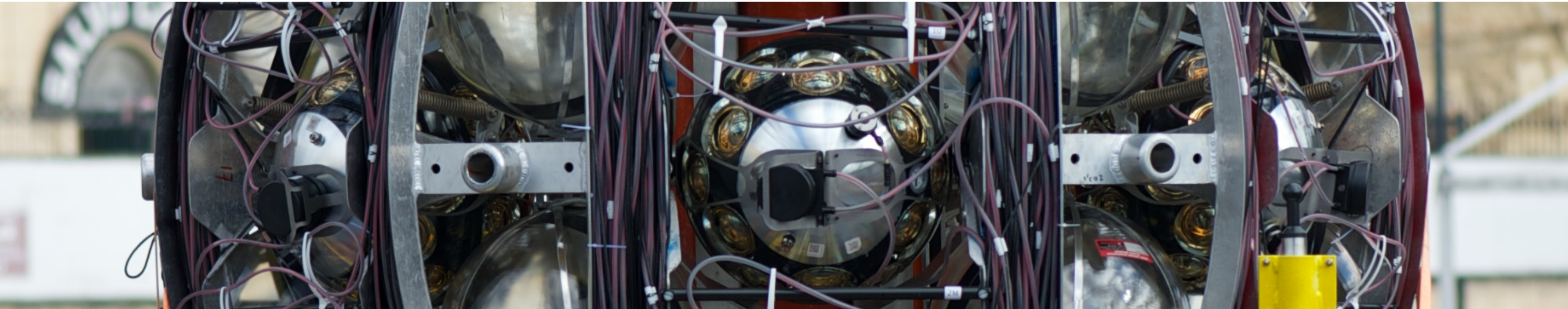
The KM3NeT Detectors



- Digital Optical Module (DOM)
  - 31 x 3-inch PMTs
  - DAQ + Calibration devices
  - Hit times and time-over-threshold send to shore
- Multi-PMT design allows for photon counting on DOM level

- Detection Unit (DU)
  - 18 DOMs
  - ARCA: DOMs ~36m apart
  - ORCA: DOMs ~9m apart
- Building Block
  - 115 DUs
  - ARCA: DUs ~95m apart
  - ORCA: DUs ~ 23m apart

Intro-Motivation



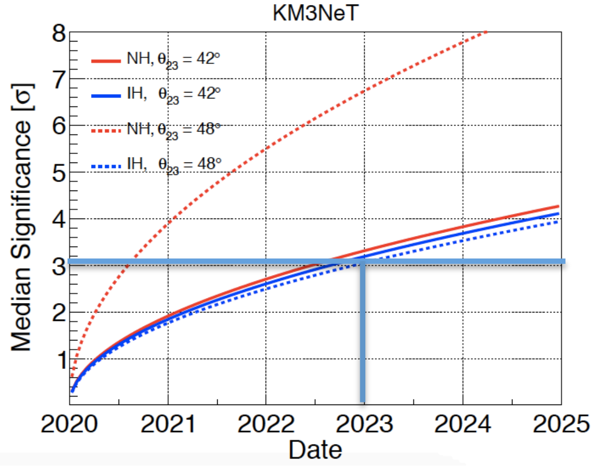
Science Objectives

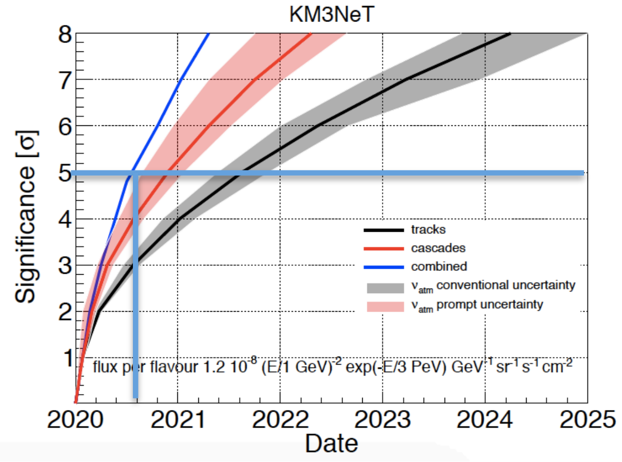
KM3NeT/ORCA

- Neutrino mass hierarchy
- Low-energy atmospheric neutrinos
- Median sensitivity: **3 sigma in 3 years**

KM3NeT/ARCA

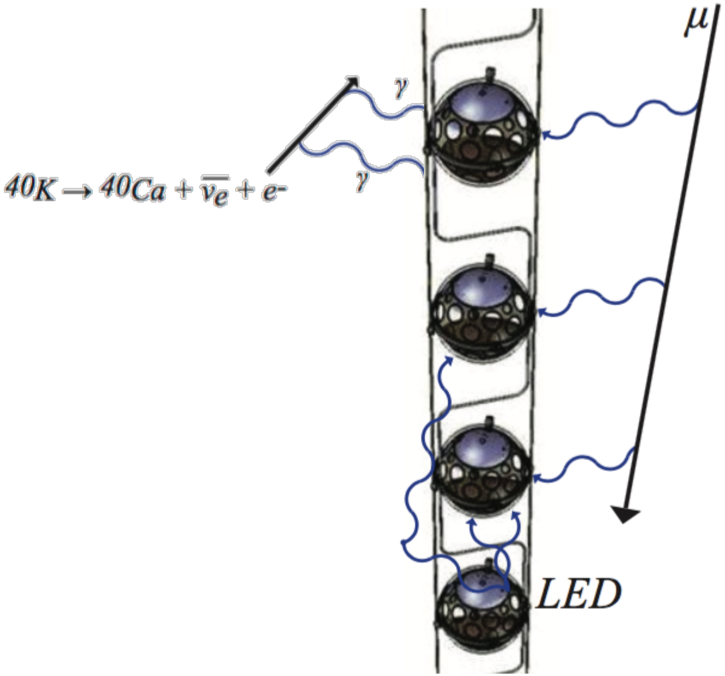
- Cosmic high-energy neutrino sources
- Diffuse flux
- Median sensitivity: **5 sigma in 0.5 year**





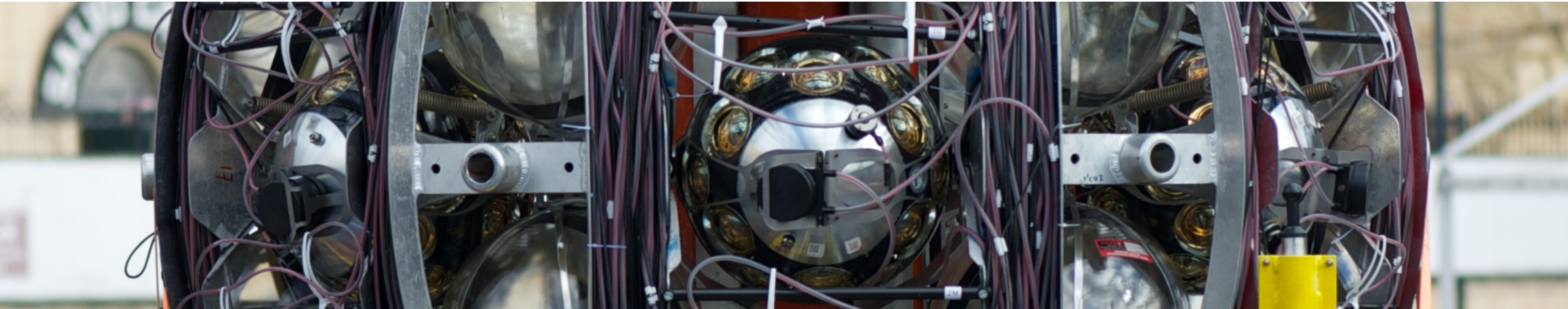
Energy and direction resolution key ingredients in both

Motivation

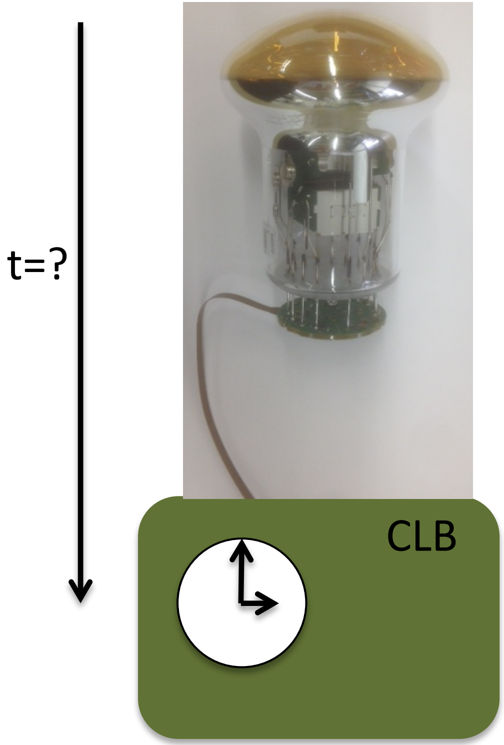


- Phase one: 3 building blocks
  - 6210 DOMs
  - 192510 PMTs
- Individual lab calibration not feasible (and inferior)
- In-situ calibration from backgrounds
  - Potassium-40 decays in sea salt
  - Atmospheric muons

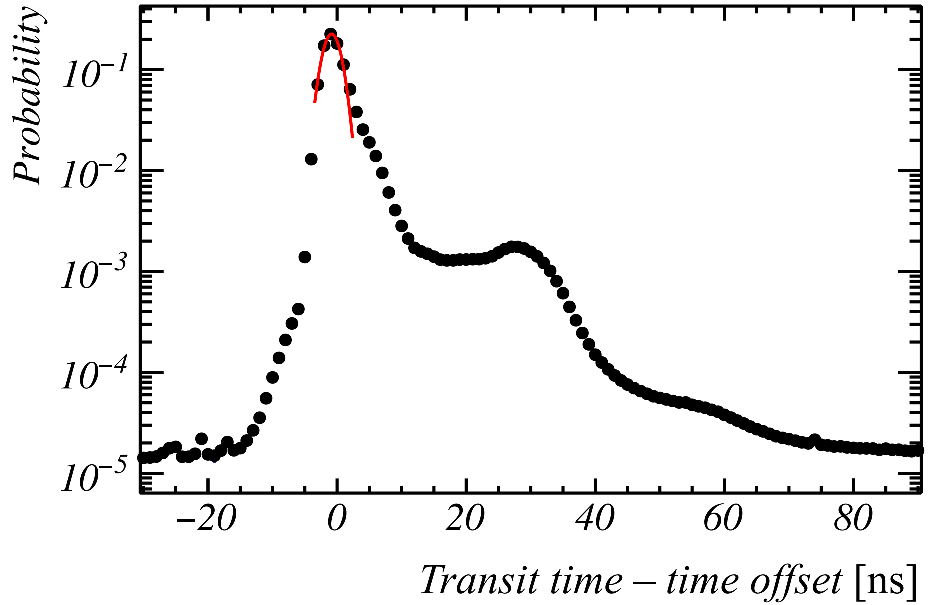
Inter-PMT Time Calibration



Inter-PMT Calibration

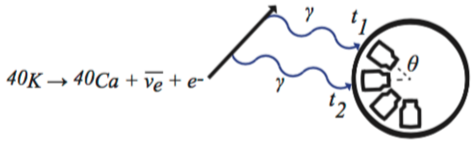


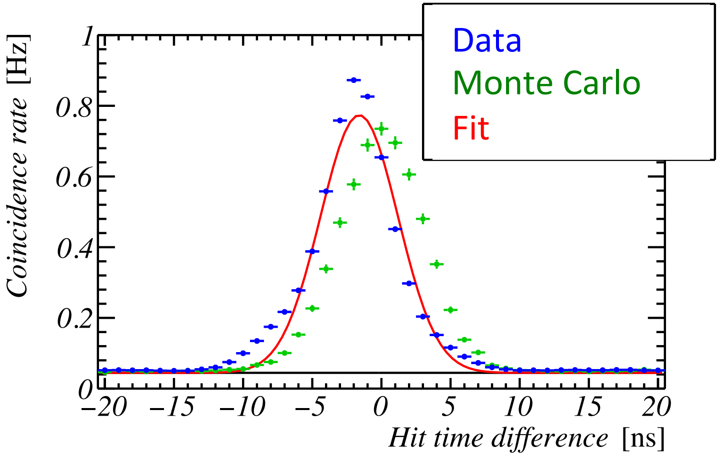
PMT transit time (TT) distribution



PMT time offset == mean transit time

In-situ ^{40}K Calibration

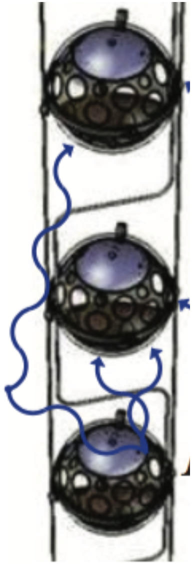


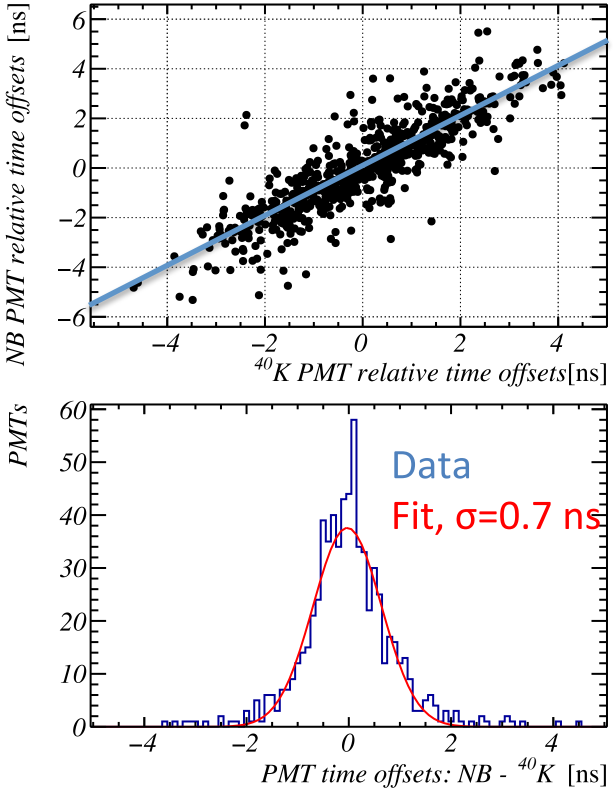


- ^{40}K coincident light on PMT pairs in DOM
  - 31*30 coincidence distributions
  - Should all peak at zero

- Simultaneous fit of all pairs
  - Mean -> Time offsets
  - Width -> Transit time spreads
  - Integral -> Efficiencies

Check with LED Nanobeacons



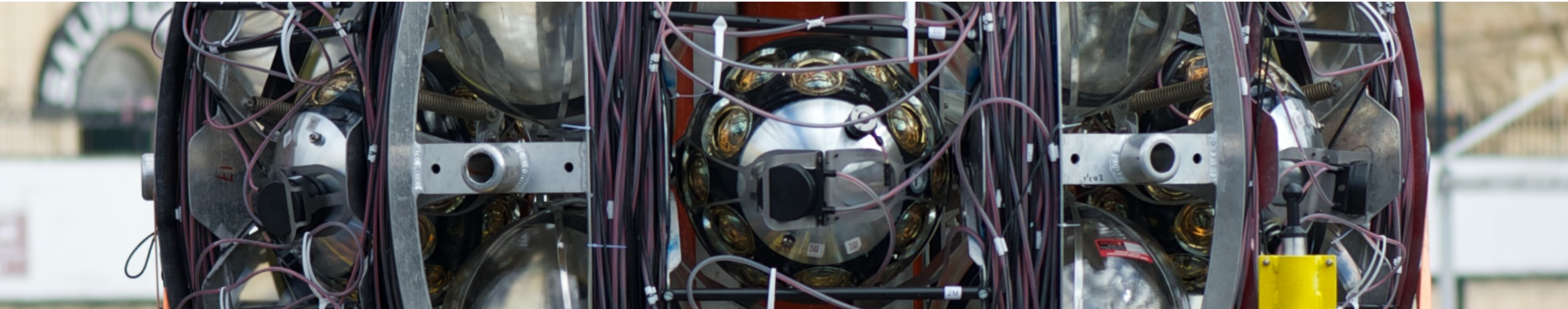


- 40K Calibration cross-checked with LED nanobeacon data

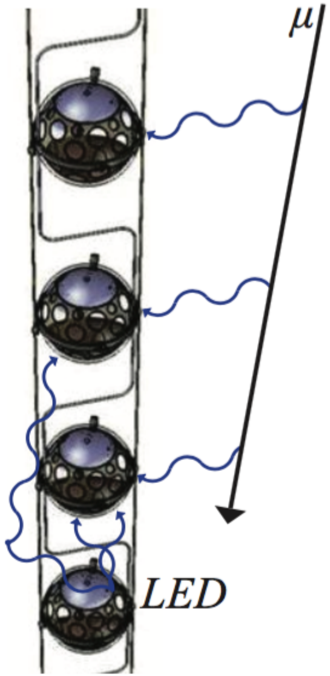
Very good agreement between methods (σ = 0.7 ns)

- Scatter (0.7 ns) expected from nanobeacon method inaccuracies

Inter-DOM Time Calibration

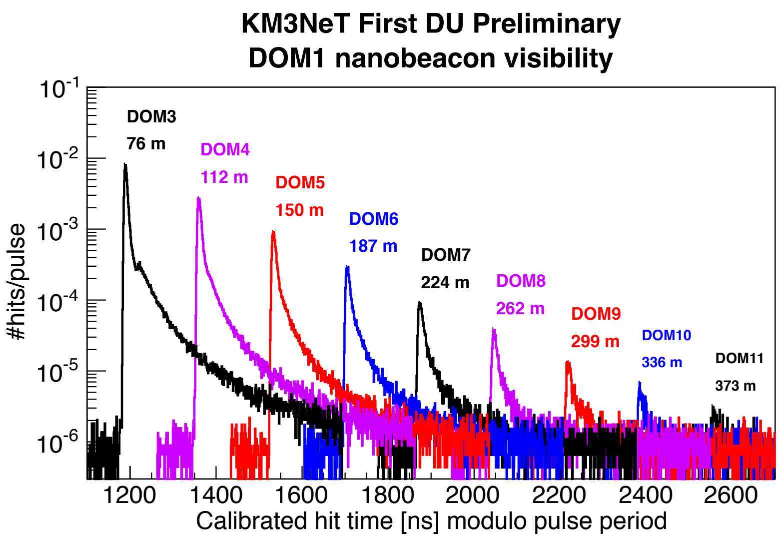


Calibration Sources



- Measure time delay of optical fibers
- LED Nanobeacons
  - Controllable source
  - High luminosity: Inter-DU
  - Low luminosity: Inter-DOM
- Atmospheric muons
  - High statistics
  - Permanent monitoring

LED Nanobeacons

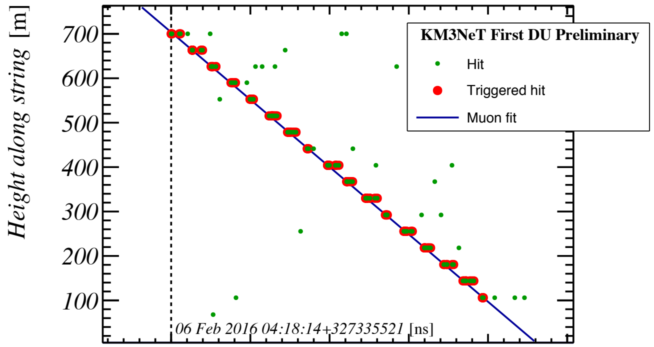


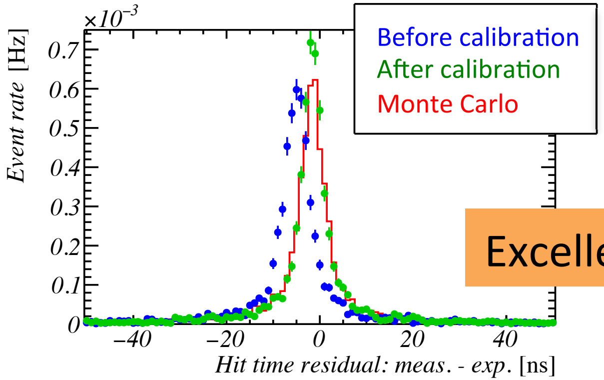
- Low luminosity: Inter-DOM calibration
- High luminosity: Inter-DU calibration
- Light can be seen up to 373 meters
- Provides (with lab. laser calibration) initial calibration for data taking

Sub-ns calibration + constant monitoring with atm. muons

*Work + plots by M. Jongen

Hit Time Residuals (HTRs)



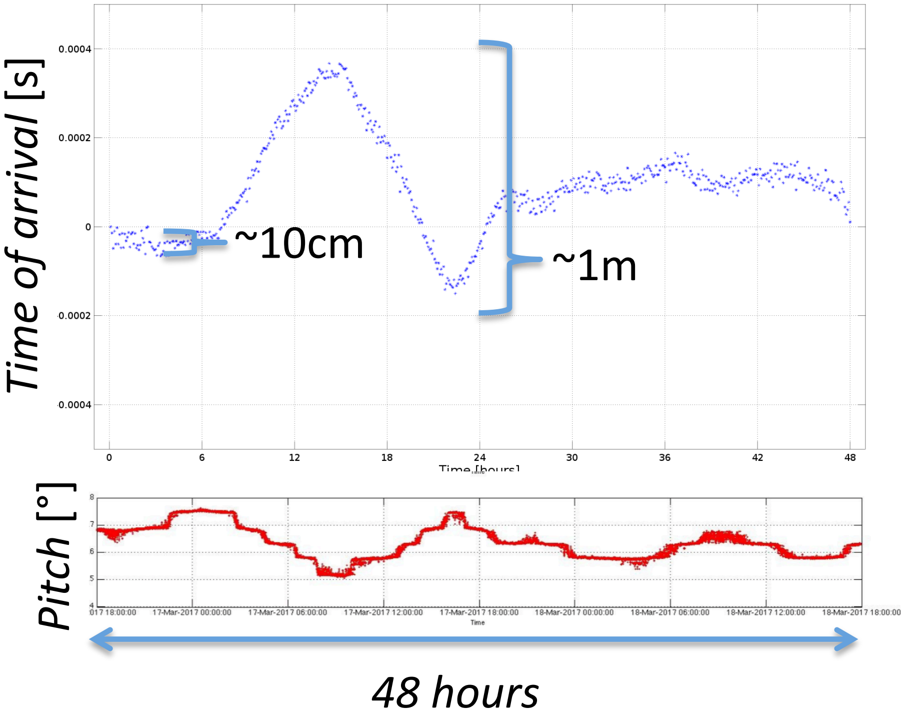


- HTR: Time difference between measured hit on a DOM and reconstructed track expectation
  - Hit DOM excluded in fit

- Shift HTR distribution with MC
- Reconstruction changes -> repeat

Excellent data-MC comparison

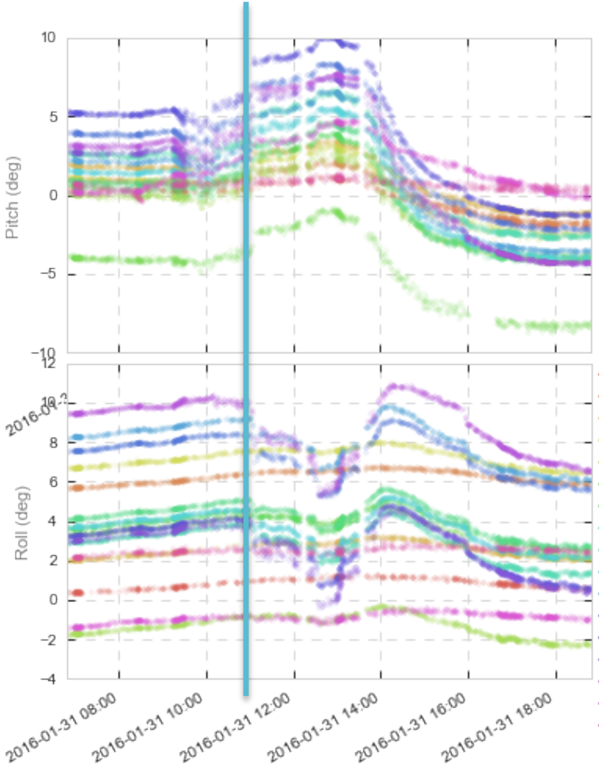
Position Variations



*Work + plots by S. Viola

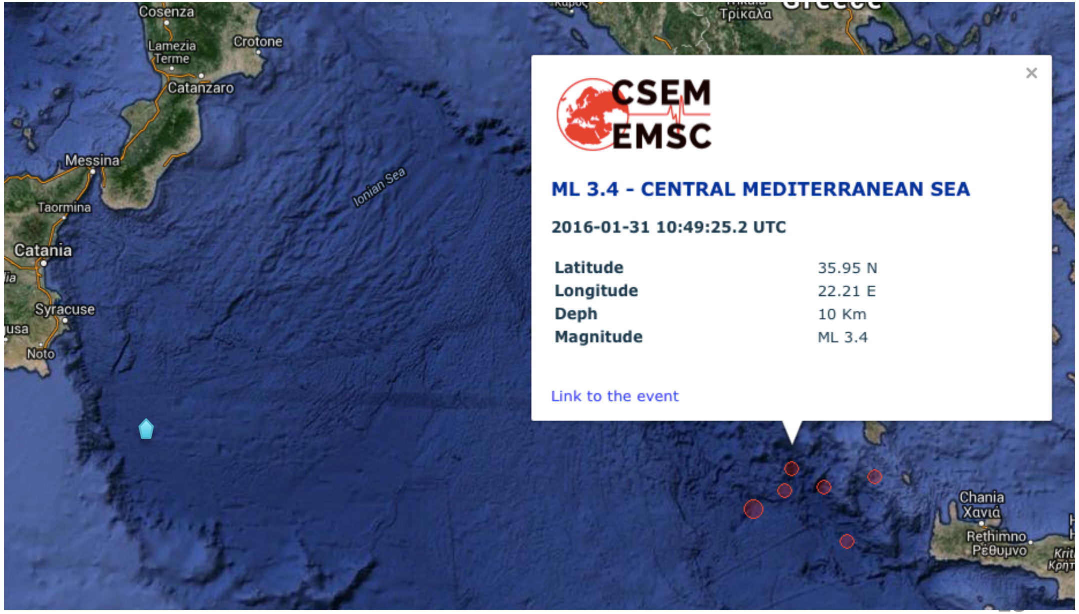
- Acoustics network to determine DOM positions with ~10cm accuracy
- ~1m position variations due to sea currents
- Also observed with DOM's compasses

Undersea Earthquake Observatory

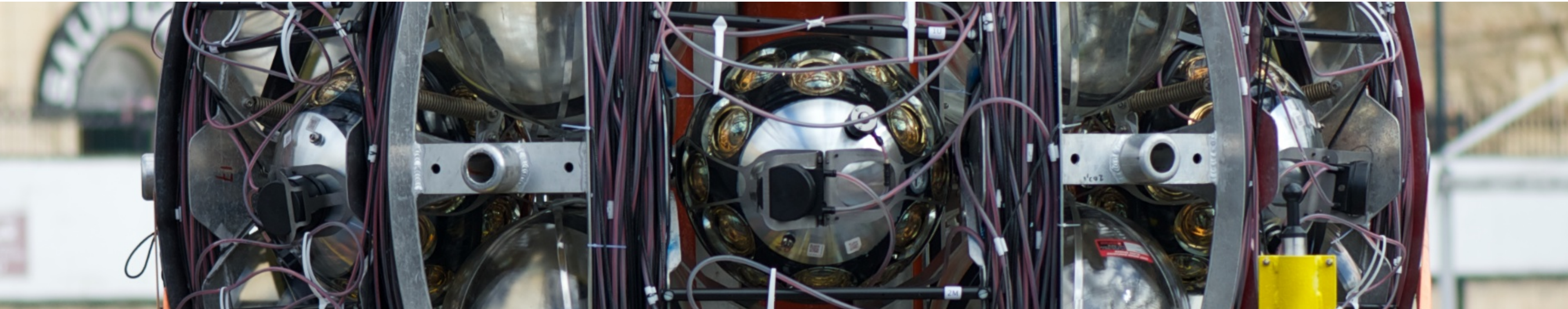


*Work + plots by D. van Eijk

Magnitude 3.4
Depth 10 km



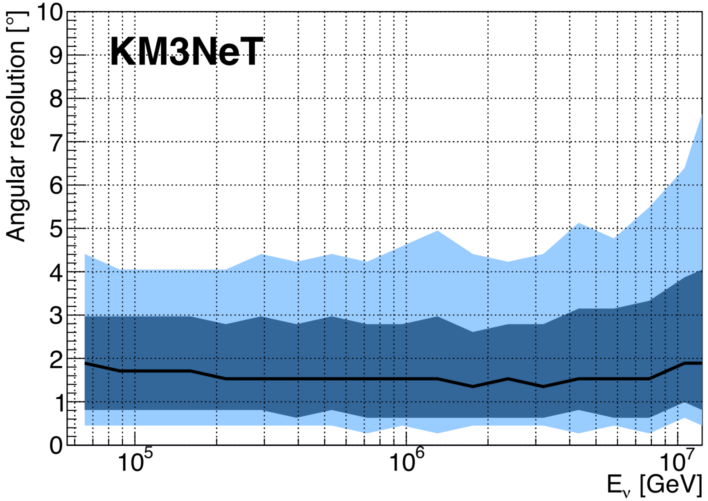
PMT Efficiencies



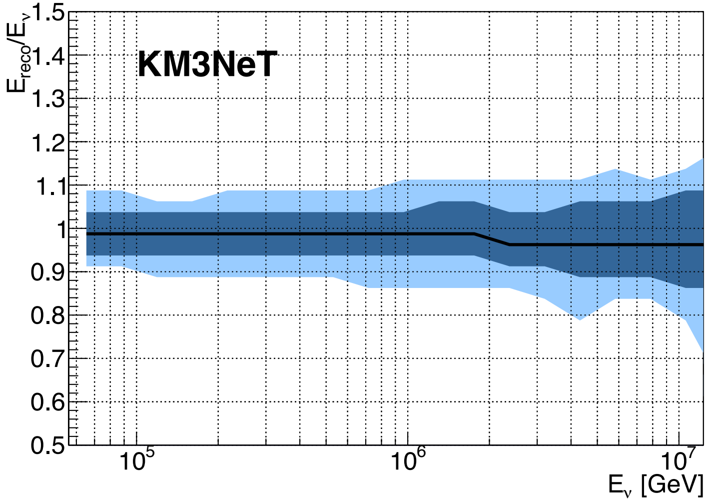
Shower Reconstruction

Only spatial distribution of PMTs hit/not hit used in reconstruction:

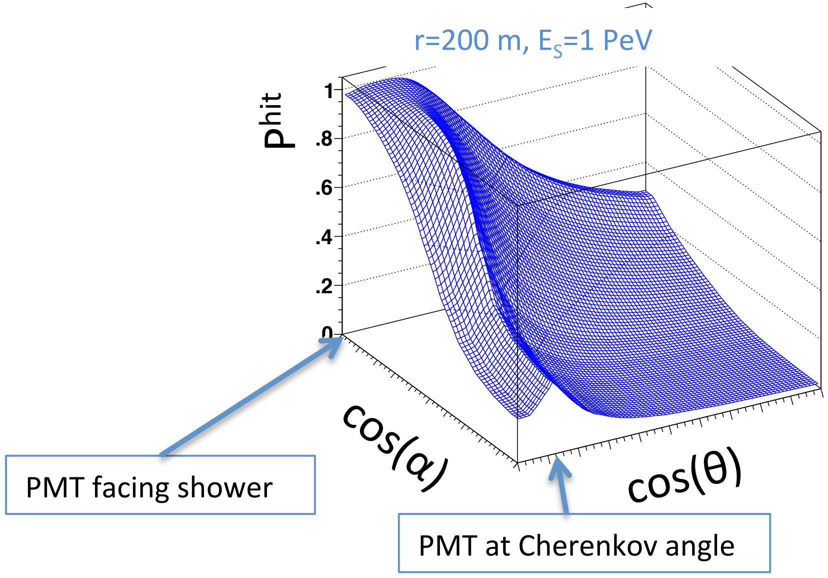
Direction resolution: ~1.5 degree



Energy resolution: ~5%



Multi-PMT Design

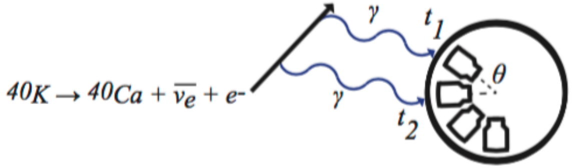


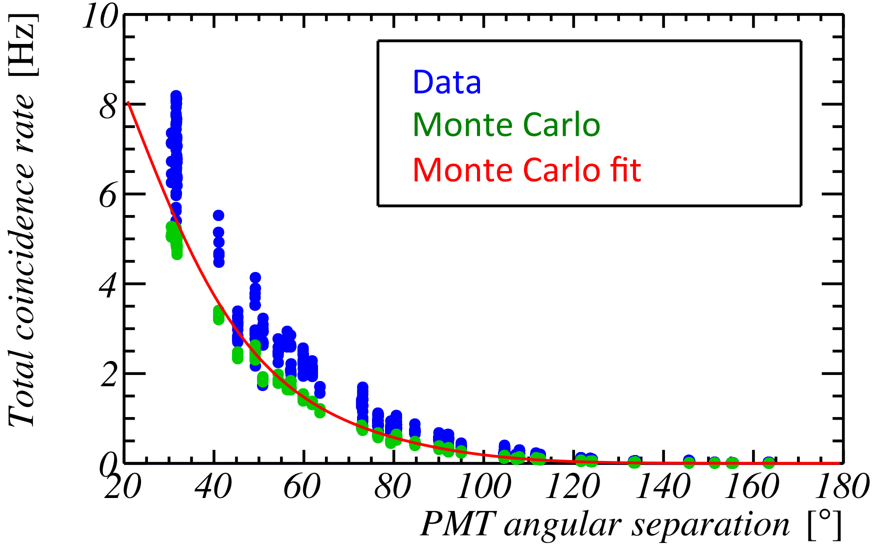
*Plot by A. Heijboer

- In shower reconstruction:
  PMT hit/not information only
- Always a sensitive set of PMTs
  - Low energy: close-by PMTs facing shower
  - High energy: distant PMTs facing away

We need to know the PMT photon detection efficiencies

PMT Efficiency Calibration



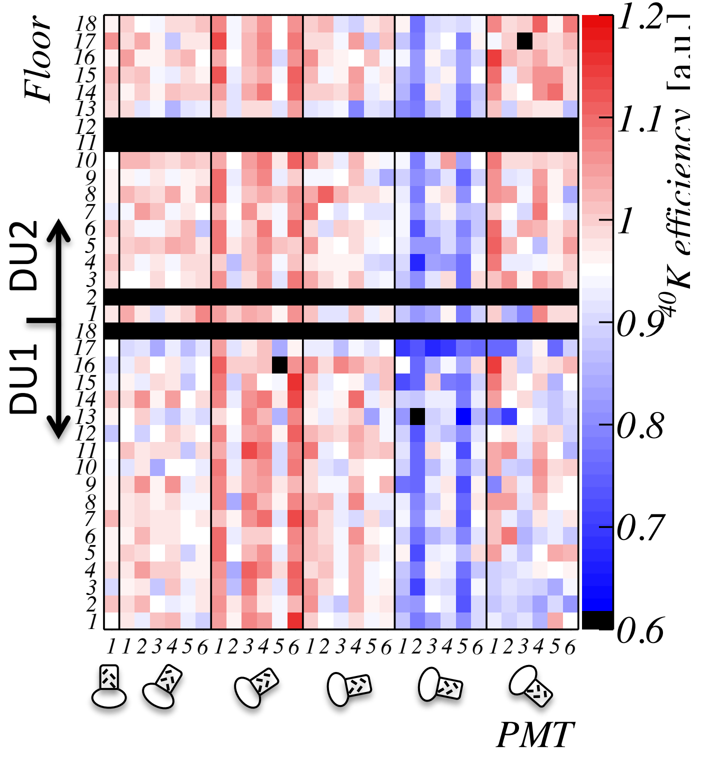


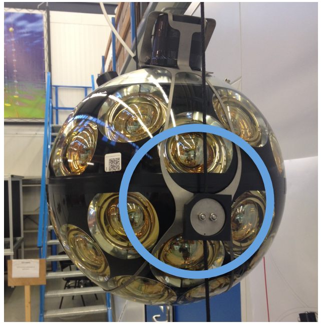
- In-situ (!) fit
  - Compare observed coincidence rates with expected ^{40}K rate

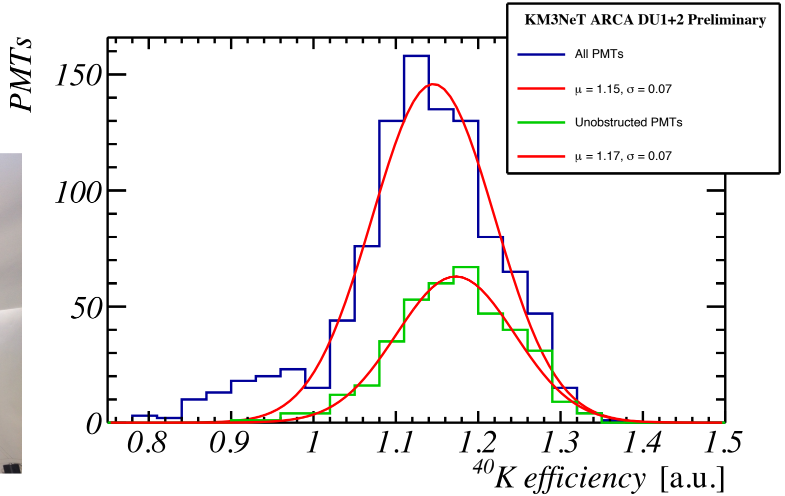
- Simultaneously fitted with PMT time offset and TTS (slide 9)

PMTs are more efficient than Hamamatsu specifications

PMT Efficiency Systematics



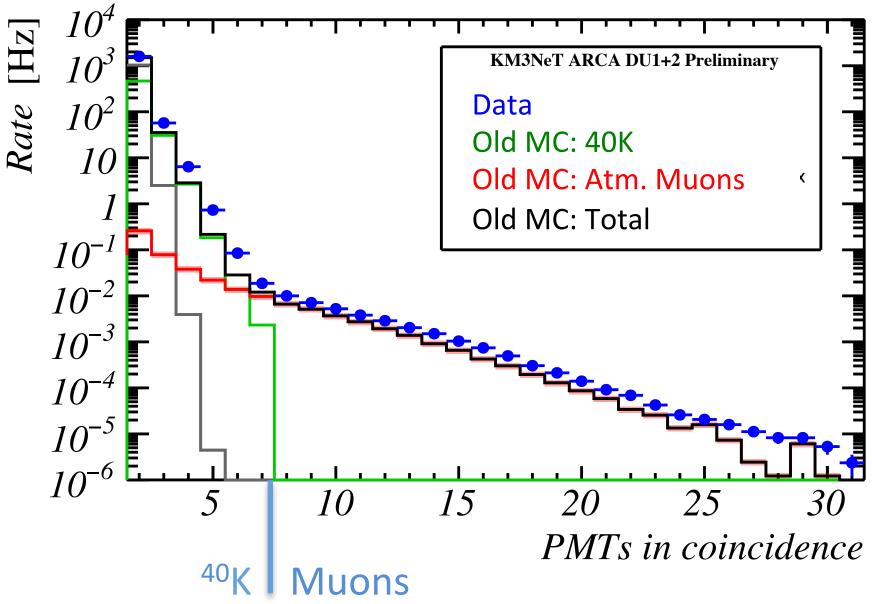




- Calibration precise enough to see collar
- PMT efficiency spread: ~6%

^{40}K MC – Muon MC - Data

Number of PMTs hit in coincidence (25ns)



- Fitted PMT efficiencies are used in run-by-run atm. muon Monte Carlo
- Excellent data-MC-MC agreement over 9 (!) orders of magnitude

^{40}K MC – Muon MC - Data

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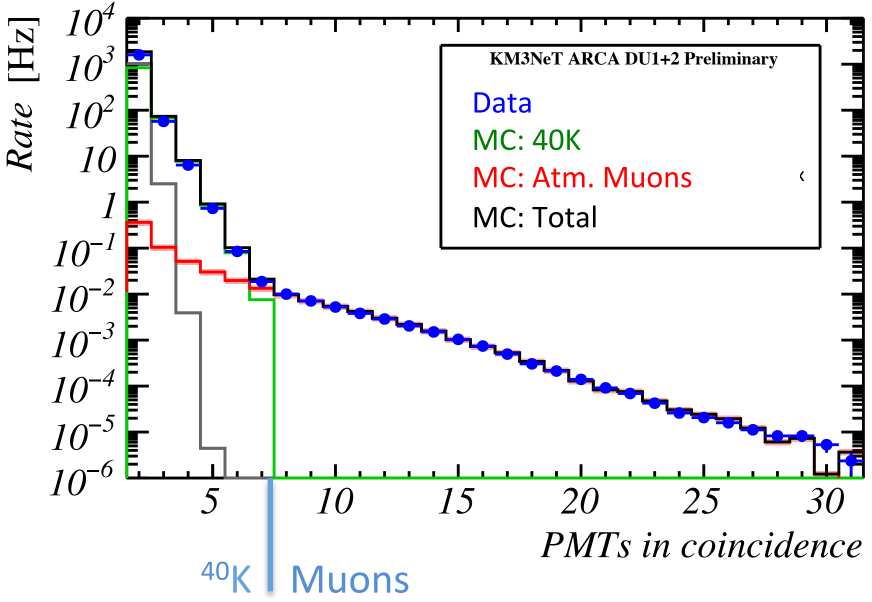

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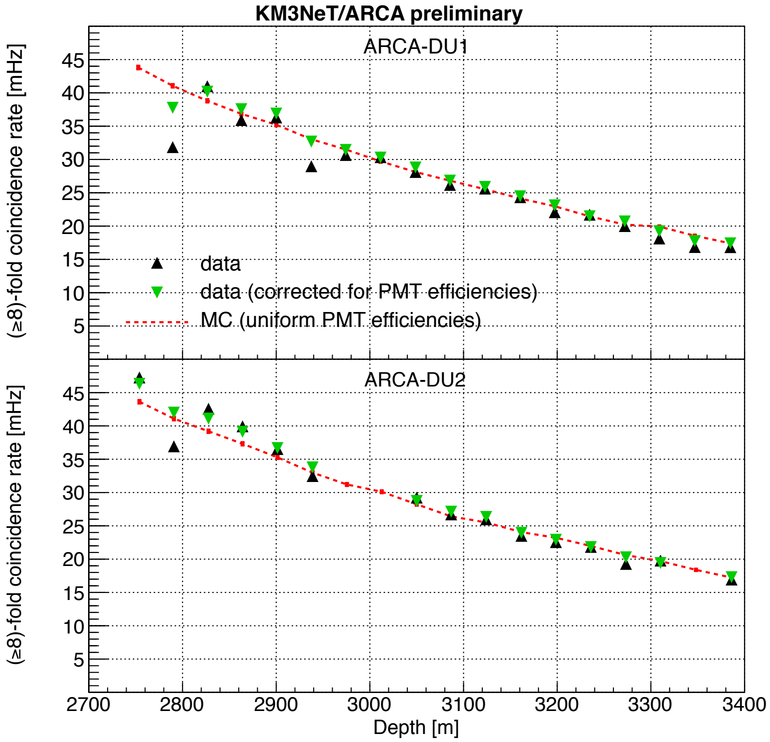
Muon Depth Dependence

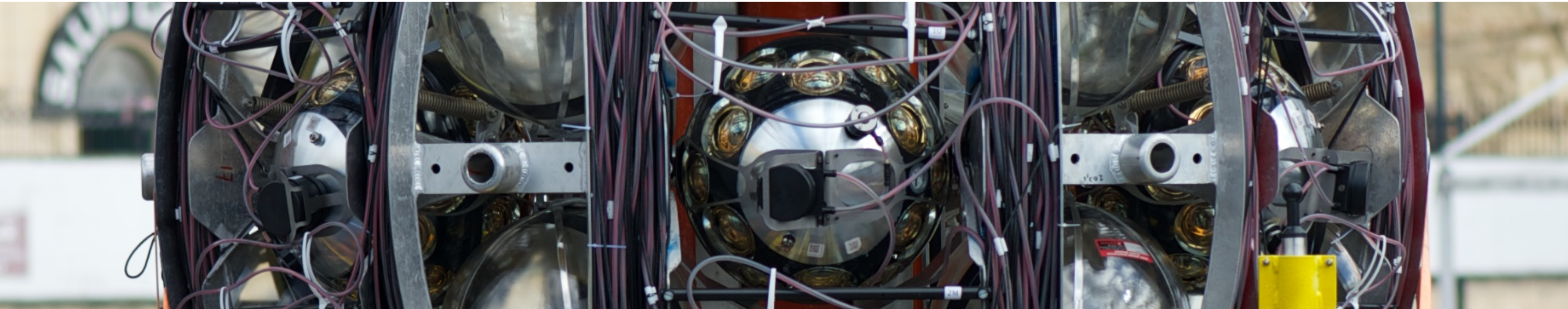


Work + plots by M. Jongen

- Multiplicity ≥8: Atmospheric muons
- Atm. muon rate decreases with depth

- Fluctuations due to different PMT efficiencies
- Rate is well-understood with PMT efficiencies from ^{40}K fit

Conclusions



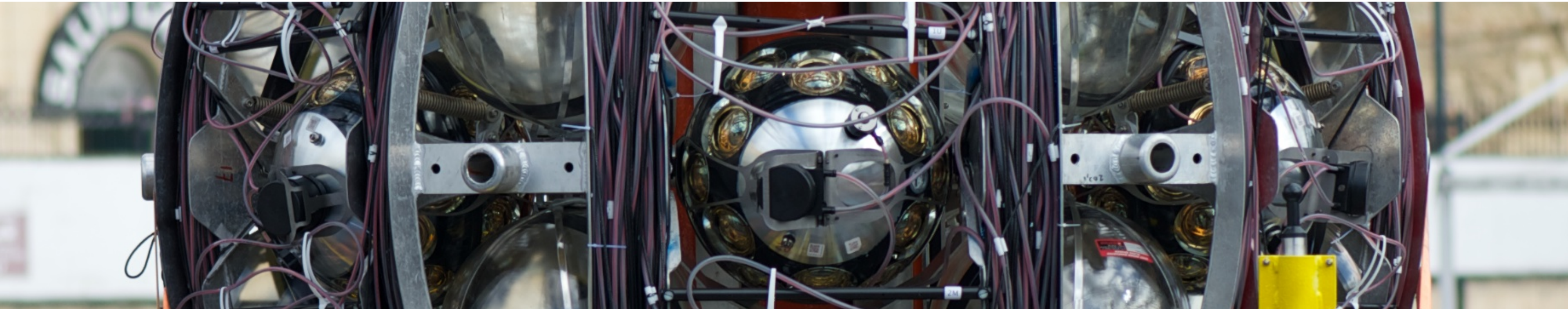
Conclusions

- Precise, constant calibration + monitoring of PMT properties:
  - **Sub-ns** time calibration accuracy
  - PMT efficiencies fitted to **percent-level** (est.)
- Excellent data - 40K MC – atm. muon MC
  - Run-by-run simulations with fitted PMT efficiencies
- Key ingredients for neutrino source searches provided
  - (And that's exactly what I'm going to do during the last year of my PhD)

Further Reading

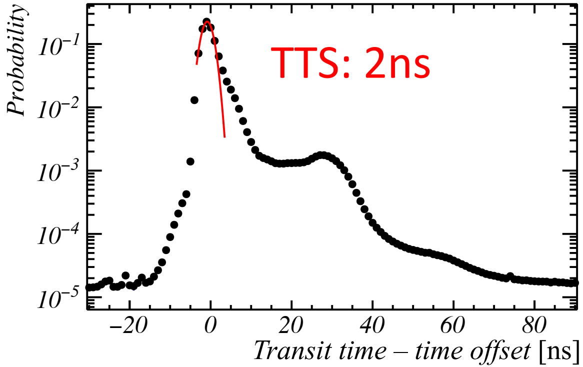
- KM3NeT Letter of Intent, J. Phys. G **43** (2016)
- In-Situ Calibration of KM3NeT, *K. Melis,* PoS(ICRC2017)1059
- All-flavour neutrino reconstruction in KM3NeT*, K. Melis, A. Heijboer & M. De Jong,* PoS(ICRC2017)950
- The KM3NeT acoustic positioning system, *S. Viola & R. Coniglione*, PoS(ICRC2017)1031
- Depth Dependence of the Atmospheric Muon Flux in KM3NeT/ARCA (in preparation)
- Characterizing the KM3NeT 3-inch Hamamatsu Photomultiplier Tube response, *A. Schermer*, master thesis

Back-Up

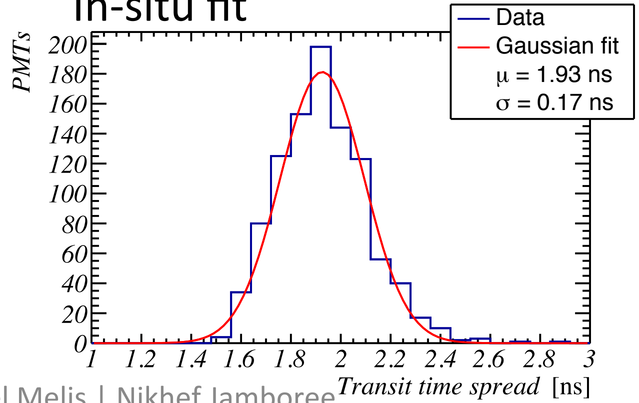


Transit Time Spread (TTS)

Lab Measurement

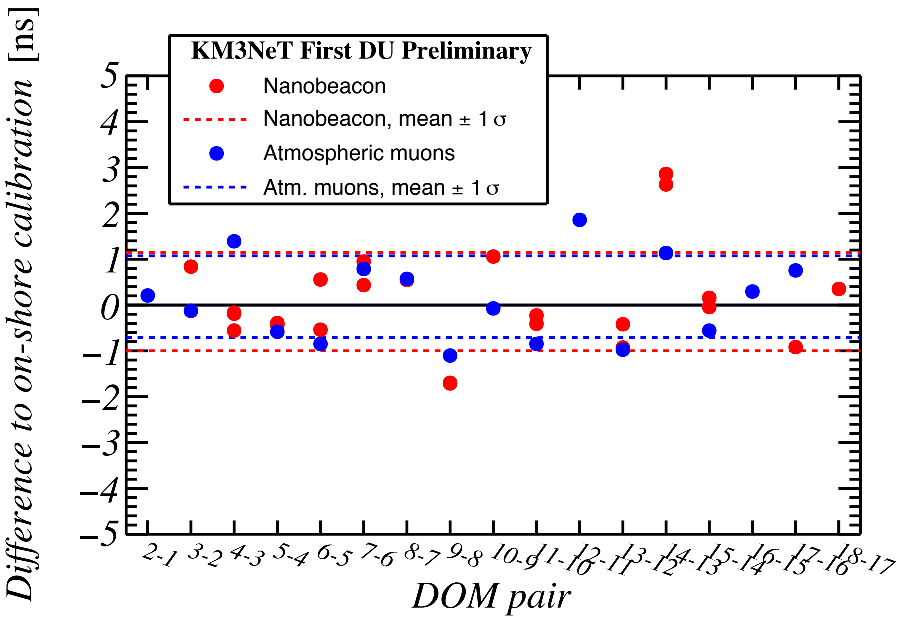


In-situ fit

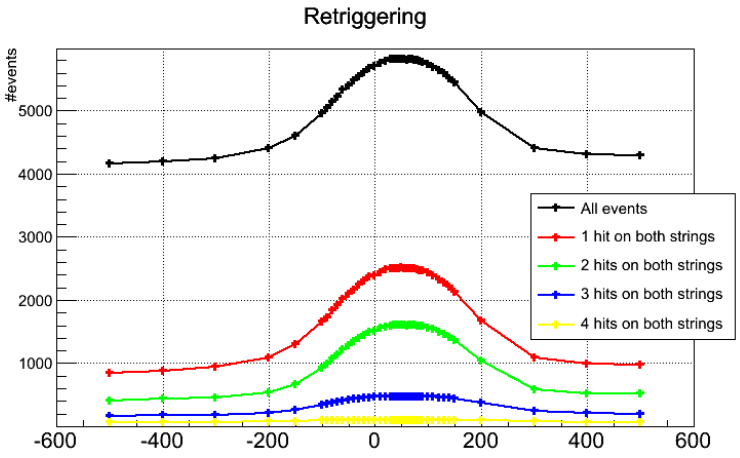


- TTS: Spread in PMT transit time
- Main factor for hit time accuracy
- In-situ fit with ^{40}K method (slide 9)
- Mean TTS (in-situ meas.): 1.9 ns
    - Compatible with lab measurements

DOM Time Cal. Comparison



Trigger Rate Optimization

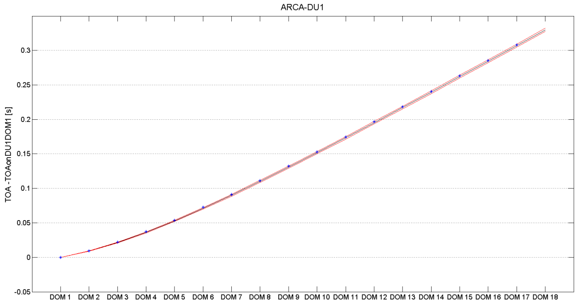


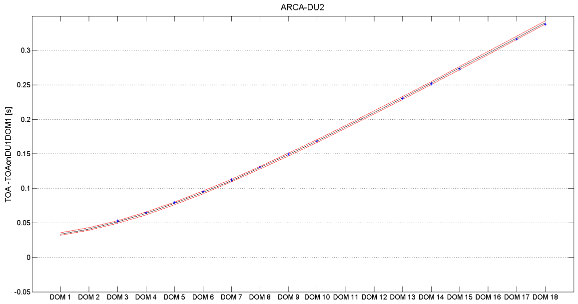
Inter-DU time offset difference – 575 [ns]

- Triggered Event:
  - At least 5 local DOM coincidences complying with track hypothesis
- Optimal DU time offset reflects in high trigger rate
- Best fit inter-DU time offset compatible with other methods (muons and LEDs)

*Work + plots by M. Jongen

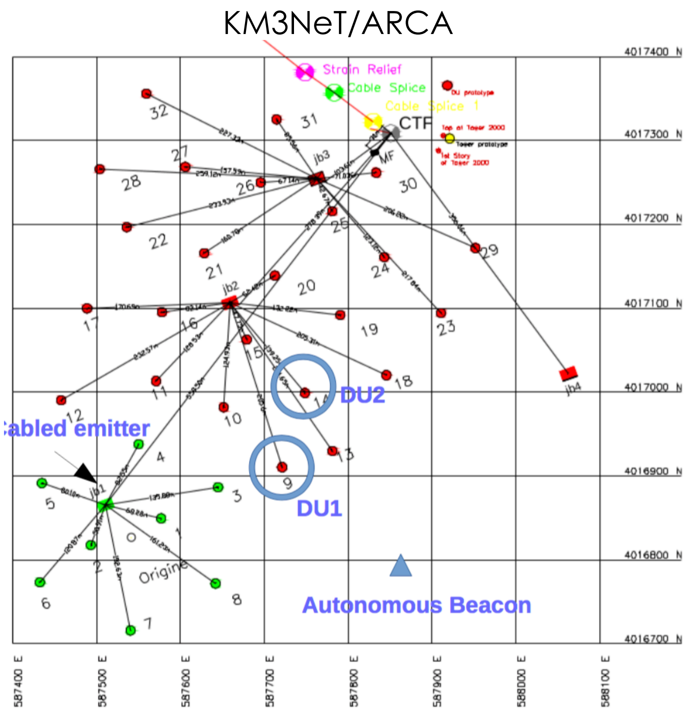
First Acoustics Data





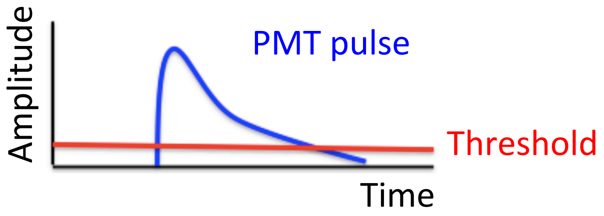
- Single emitter
  - No fit of DOM positions
- Comparison of time-of-arrival of sound with vertical DU

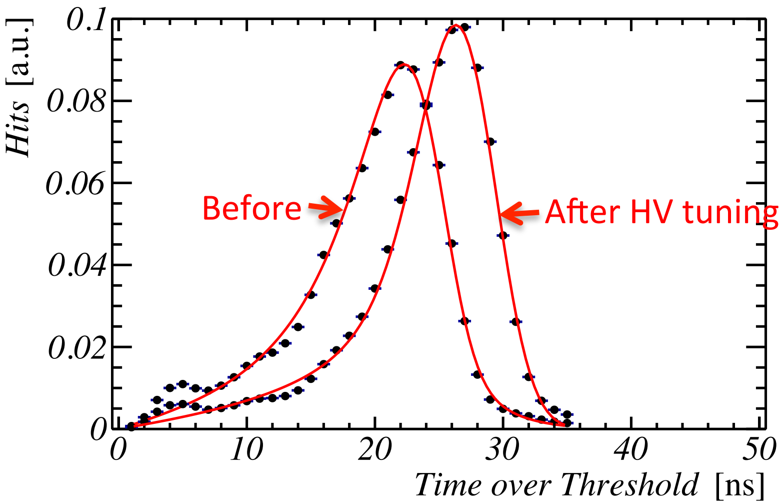
Acoustic Network



- Piezo-based microphone in each DOM.
- Acoustic emitters on seabed
  - Sound range: 8km
- Distance emitter-DOM from triangulation of time-of-arrival measurements

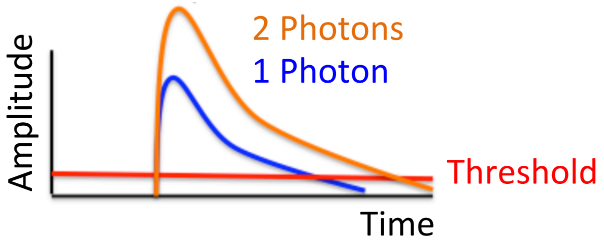
Time over Threshold

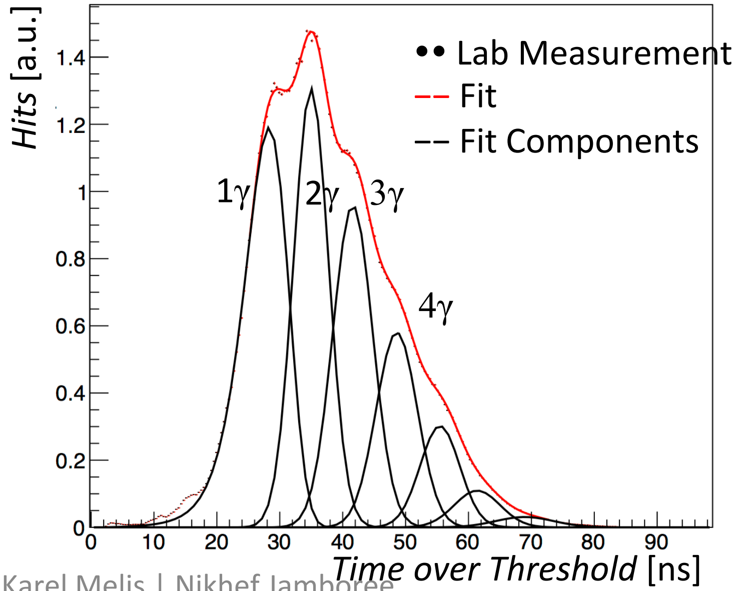




- All-data-to shore principle
  - Not feasible to store all PMT pulse
- Number of hit photons from pulse Time over Threshold (ToT)
- In-situ high voltage tuning of PMTs to give single photon ToT=26 ns.

Photon Counting Capability





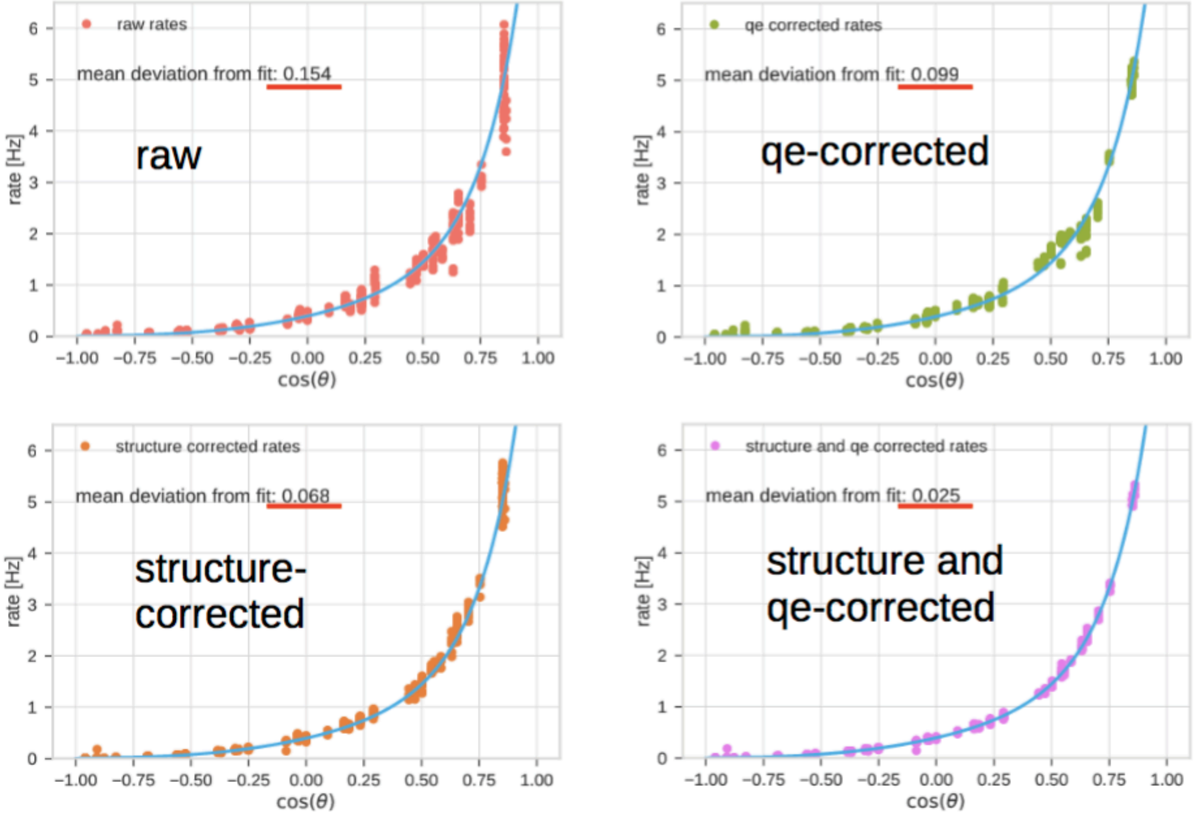
- Number of photons can be estimated from Time over Threshold (ToT)

- Fairly simple model describes data very well
  - Only sigma's and laser amplitude fitted

Q: What can we achieve without photon counting?

*Work + plots by B. Schermer

PMT Systematics



*Work + plots by J. Reubelt & J. Hofestädt