Noise modeling for the multi-PMT digital optical modules of the IceCube Upgrade

Flash Talk

Nora Feigl, 26.10.2023
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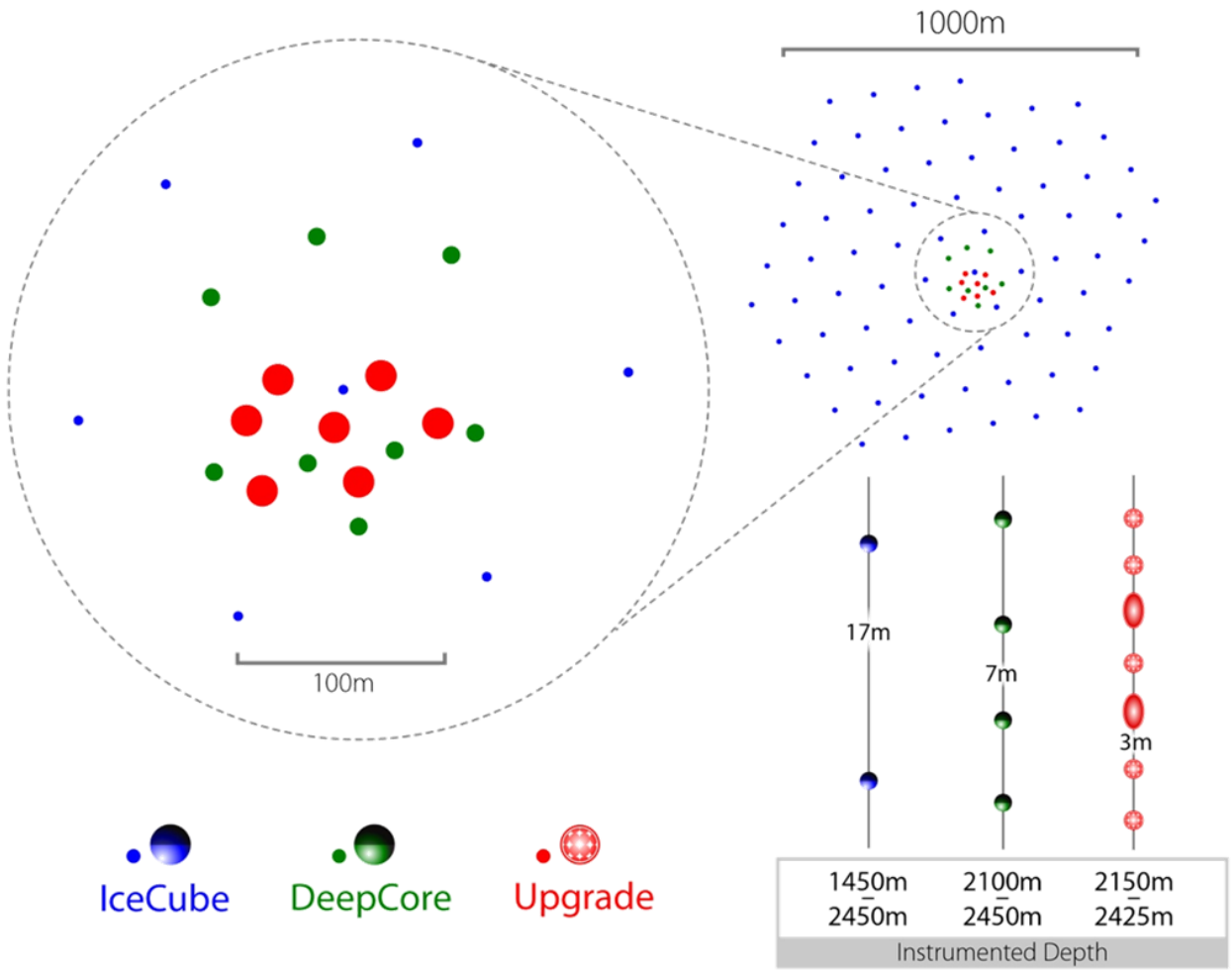
HELMHOLTZ

Introduction to the IceCube Upgrade and the mDOM

low-energy extension to be installed in 2026

- **IceCube**: ~100 GeV energy threshold
- **DeepCore**: densely spaced subdetector → lower energy threshold (~10 GeV)
- **Upgrade**:
  - reduce energy threshold to a few GeV

  → new quality of atmospheric neutrino oscillation measurements
  - improve detector calibration



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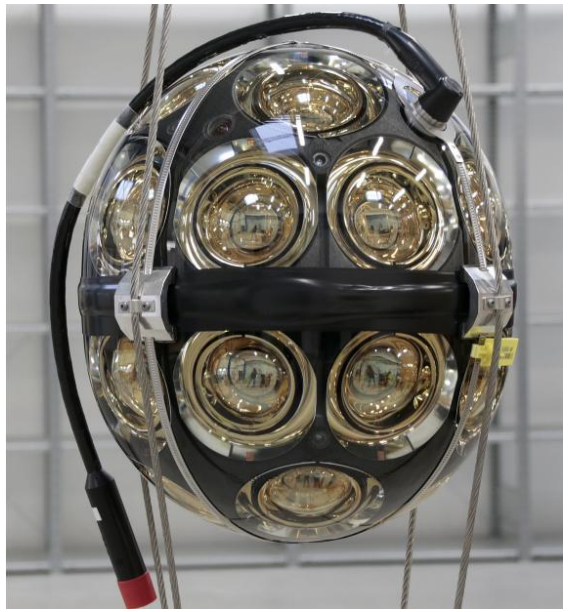
IceCube DOM



IceCube Upgrade mDOM

Unwanted photons due to dark noise: a problem?

radioactive decays in the mDOM

- **important mDOM dark noise source**: about 3000 decays per second in the mDOM
- ^{40}K and isotopes from decay chains of ^{238}U, ^{235}U and ^{232}Th → α and β decay
- α and β particles produce photons through **Cherenkov radiation** and **Scintillation**

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→ noise models A, B and C

Model A: expected isotope activity, T= -20°C
Model B: **+10% activity of all isotopes**, T= -20°C
Model C*: expected isotope activity, **T= -30°C**

 *) Simulation for -30°C preliminary: scintillation parameters for this temperature have not been measured yet for the PMTs, only estimated.

What changes result from the different noise models?

Δ*t* distribution based on GEANT4 simulation

- time difference *Δt* between subsequent photon hits
- **Noise components in Δ*t* distribution**:
  - correlated noise: **Cherenkov** emission and **scintillation** photons
  - **uncorrelated noise**

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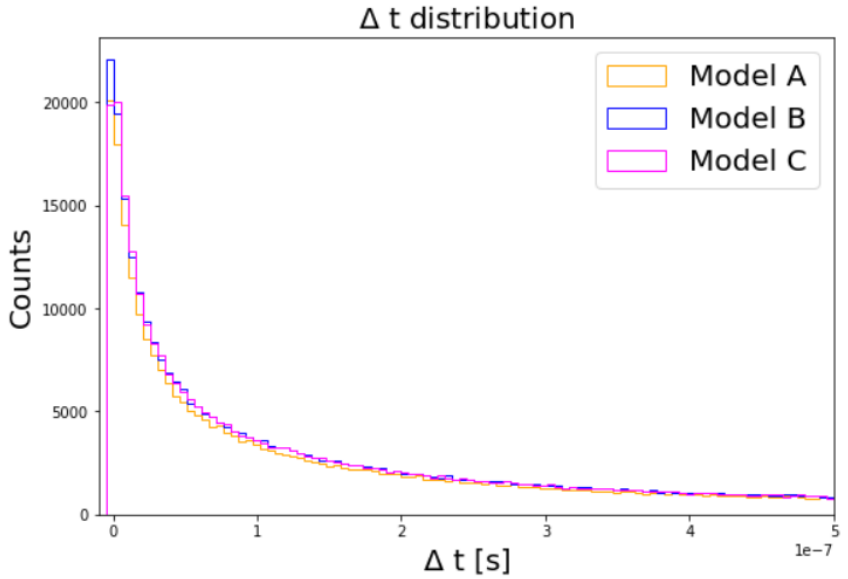

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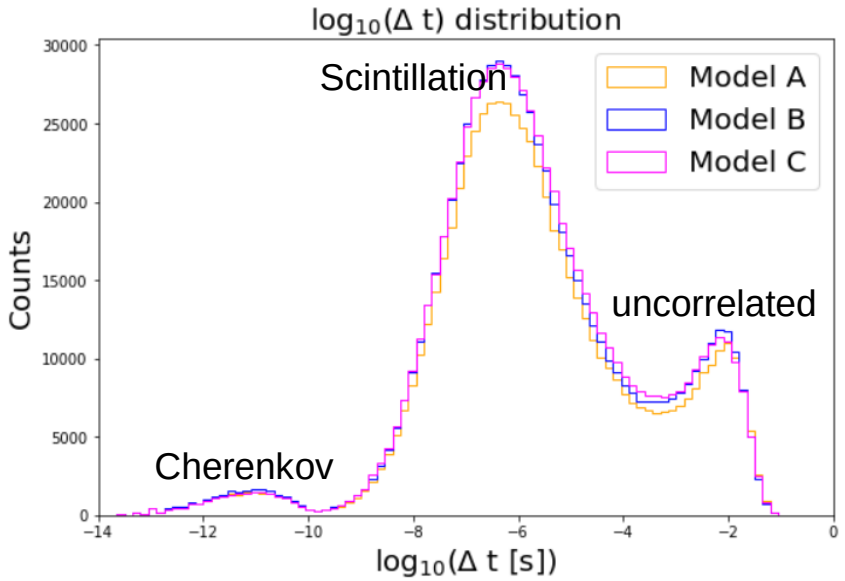

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Effects on signal to noise ratio

altered noise at different energies

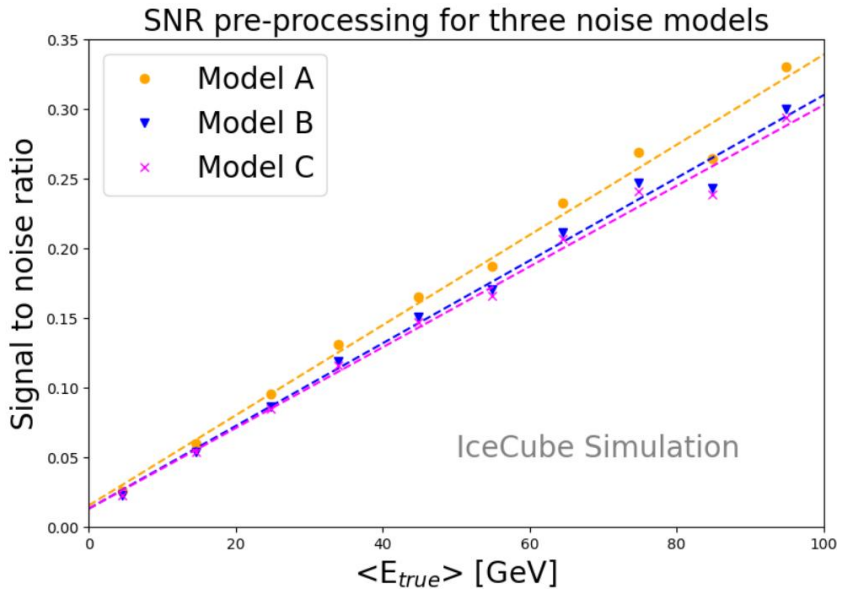
IceCube Upgrade Monte Carlo Simulation:

1. neutrino event* and detector simulation + noise
2. filtering, noise cleaning, reconstruction…

- simulated ν_μ events were processed with noise models A, B and C

- **figure**: Signal to noise ratio (SNR) of all three models before event processing (2.)

→ But how does a change in the signal to noise ratio affect reconstruction?



 *) With GENIE https://github.com/GENIE-MC

Dark noise: a problem?

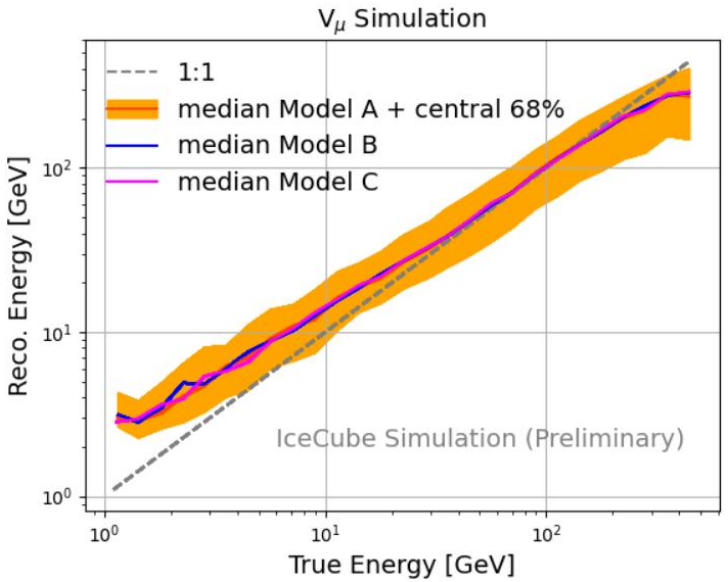
after filtering, noise cleaning etc.

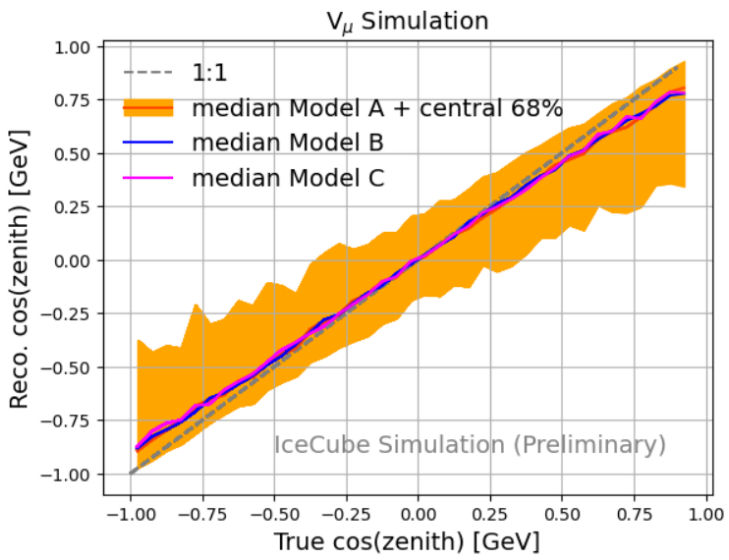
energy and zenith reconstruction:

- after event processing
- detector simulation (→ *all* modules)

→ no degradation of resolution

… But how accurate are the noise models?





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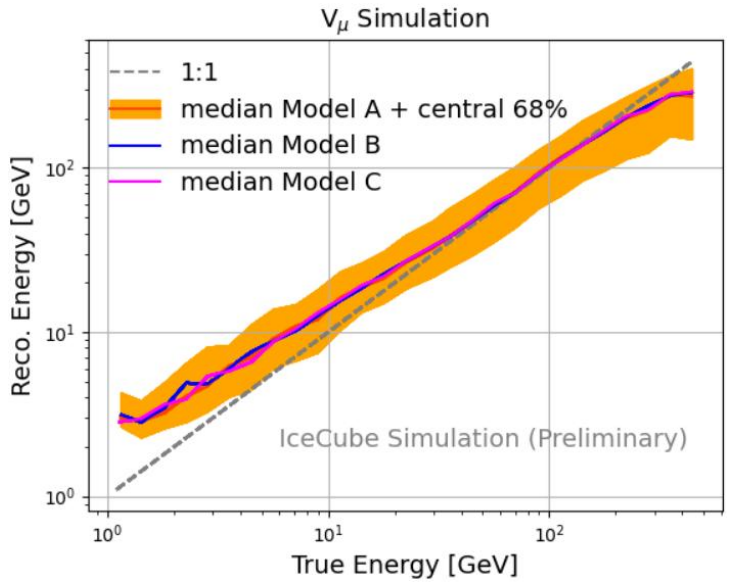
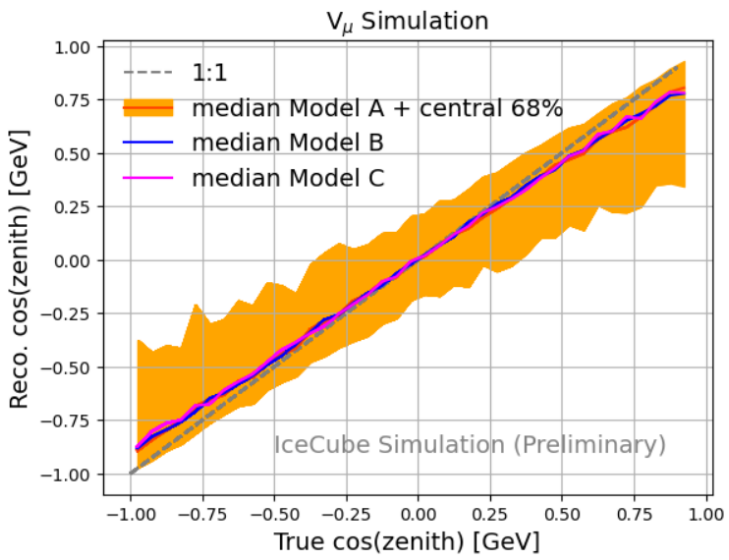
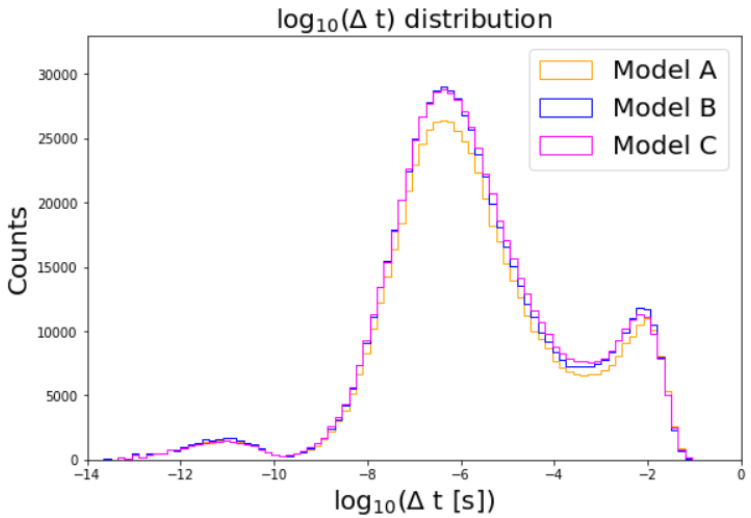
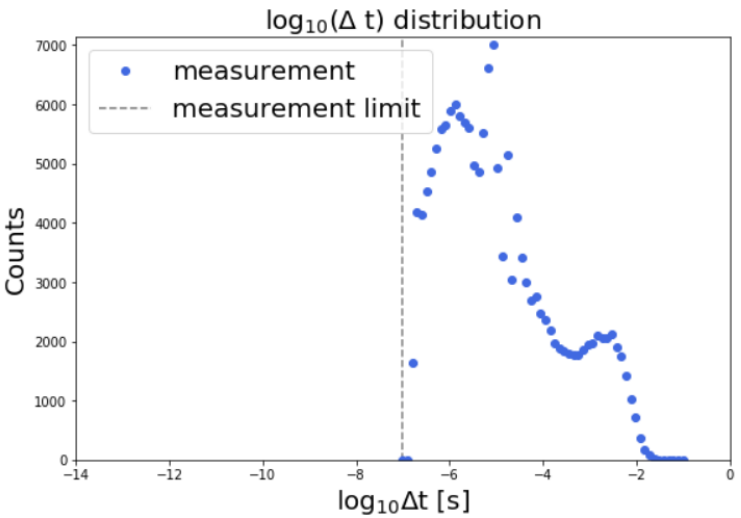
→ **next step**: compare *Δt* distribution with dark noise measurements

- first figure (temperature = -13°C)









Further Information

Noise modeling for the multi-PMT digital optical modules of the IceCube Upgrade

- **Abstract:** The IceCube Upgrade, to be installed in 2026, is a low-energy extension of the DeepCore detector part of the IceCube in-ice Cherenkov neutrino telescope at the South Pole. The Upgrade will improve the detection of neutrino interactions in the GeV range by deploying nearly 700 new multi-PMT digital optical modules in a high-density configuration. This allows for more precise measurements of fundamental physics phenomena such as neutrino oscillations and searches for beyond the Standard Model physics. In this presentation an important background to consider for these low-level signals is discussed: the intrinsic noise caused by radioactive decays in the optical module's glass components. This background is modeled using GEANT4, which accounts accurately for correlated hits on short time scales across PMTs within a single module and can be calibrated against measurements of the module testing prior deployment.

- **Primary author:** Nora Feigl (PhD student; Humboldt-Universität zu Berlin)
- **Co-authors:** Summer Blot (supervisor; DESY), Marek Kowalski (supervisor; Humboldt-Universität zu Berlin, DESY)
- **Organization (collaboration):** IceCube Neutrino Observatory

- **Key-word and topic of presentation:** Dark noise modeling
- **Related work:** PhD thesis by Martin Antonio Unland Elorrieta (DOI 10.5281/zenodo.8121321)