Dark rates induced by radioactive decays in optical modules for neutrino telescopes

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Background from radioactive decays

- Photons from radioactive decays in glass of optical modules (via Cherenkov & scintillation) are an important background source for neutrino telescopes like IceCube and KM3NeT
- Scintillation parameters (yield, lifetime, spectrum): very sensitive to material composition
  → Investigation of glass samples from **Benthos** (IceCube) and **Vitrovex** (KM3NeT)

Measured radioactivity of the glass

Mass-specific activity (Bq/kg)

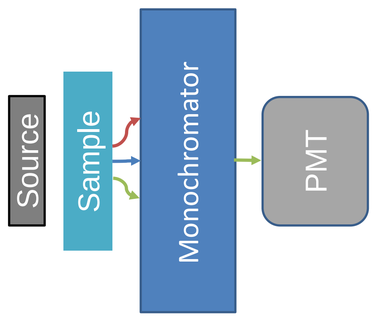
	Vitrovex 1	Vitrovex 2	Benthos 1	Benthos 2
^{238}U-Chain	4.61 ± 0.07	4.59 ± 0.10	3.67 ± 0.10	5.20 ± 0.12
^{235}U-Chain	0.59 ± 0.05	0.62 ± 0.16	0.30 ± 0.12	0.61 ± 0.09
^{232}Th-Chain	1.28 ± 0.06	1.07 ± 0.10	0.76 ± 0.09	1.16 ± 0.09
^{40}K	61 ± 1	<0.99	5.3 ± 0.6	1.0 ± 1.4

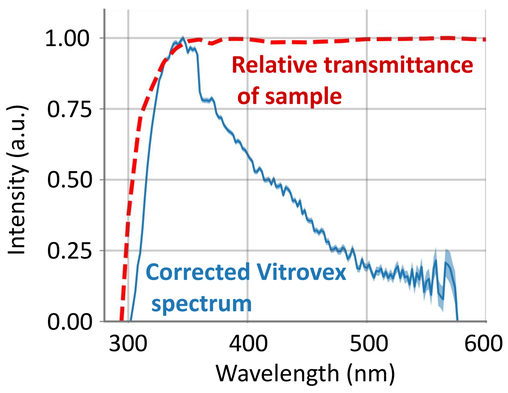
- Vitrovex 1: Average of 3 Vitrovex samples from 2016
- Vitrovex 2: Old Vitrovex prototype vessel (production year ~2000)
- Benthos 1 &2: Sample from DOM pressure vessel

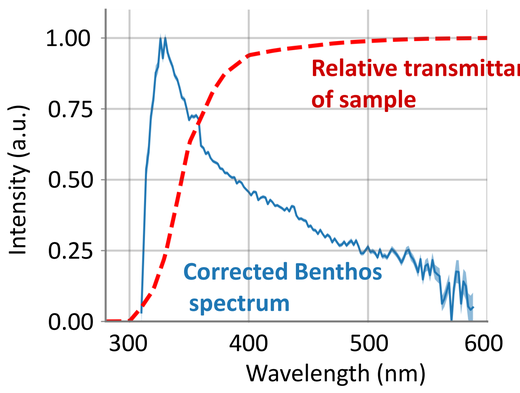
Measuring scintillation parameters

Scintillation spectrum

- Excitation of samples with radioactive source
- Measurement of spectrum with monochromator and PMT
- Best results with ^{90}Sr (~0.4 GBq)
- Corrected for monochromator efficiency, PMT efficiency and sample transmittance

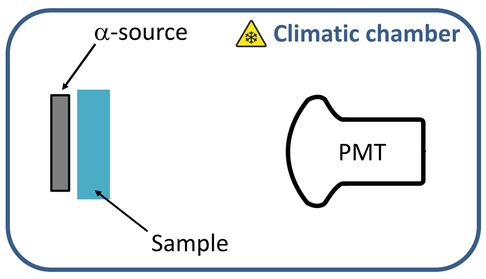


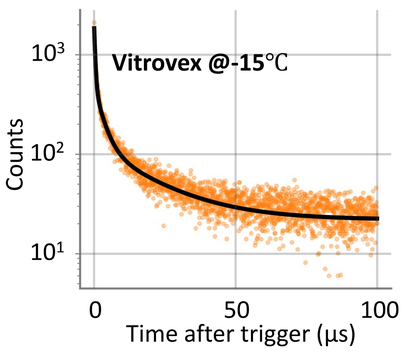


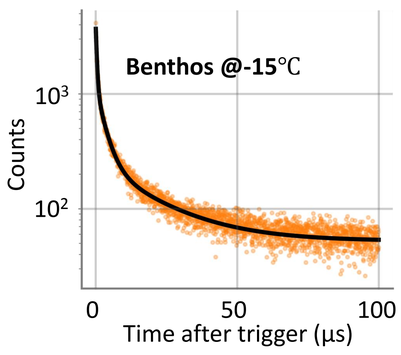


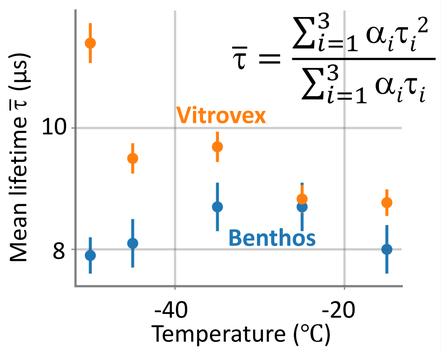
Scintillation lifetime

- Excitation with weak Am source (~2.83 kBq)
- Record long waveforms and determine time of photons with respect to first photon
- Multi-exponential decay fit (3 decay constants)
- Corrected for PMT afterpulsing and bias due to unknown radioactive decay time



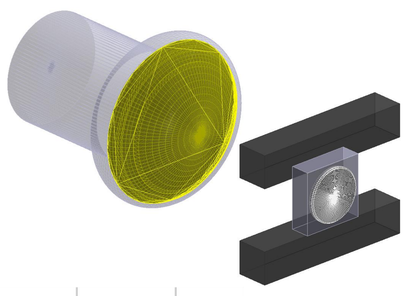


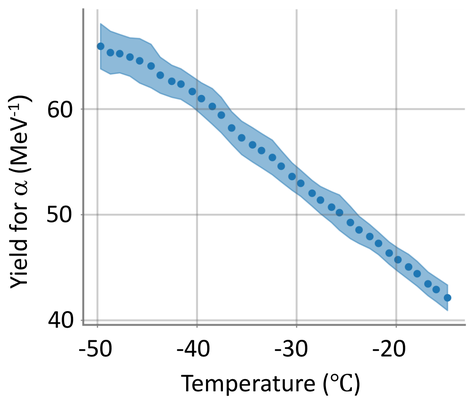


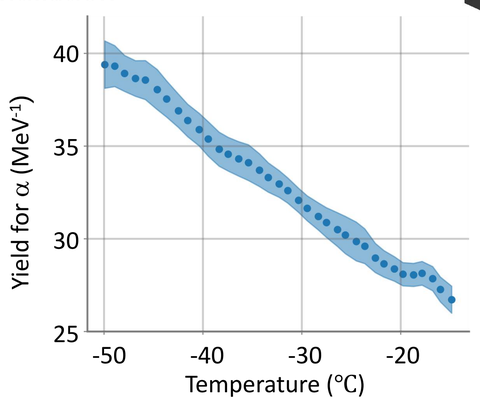


Scintillation yield

- Yield: mean number of emitted photons per MeV
- Measure rate from excited sample in *lifetime setup*
- Compare measurement to simulation and adjust yield in simulation to match measured rate
- Corrected for PMT dark rate and air scintillation





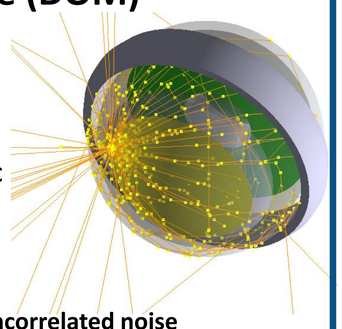


Phonon emission increases with temperature → decrease of yield

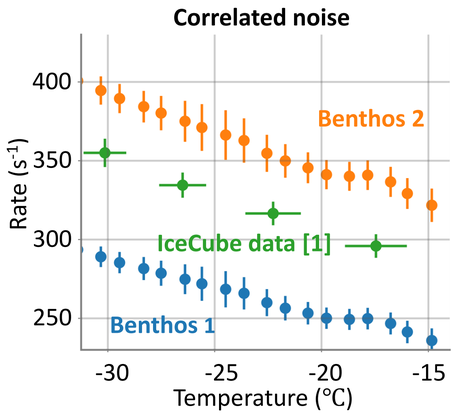
Simulation of decays in IceCube module (DOM)

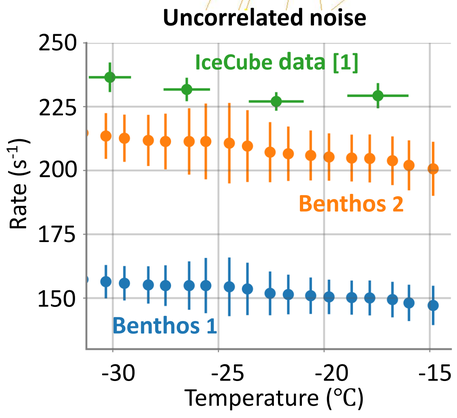
Simulation parameters (Geant4)

- Module geometry + optical properties
- Measured Benthos scintillation properties
- Module enclosed in ice with realistic absorption and scattering length



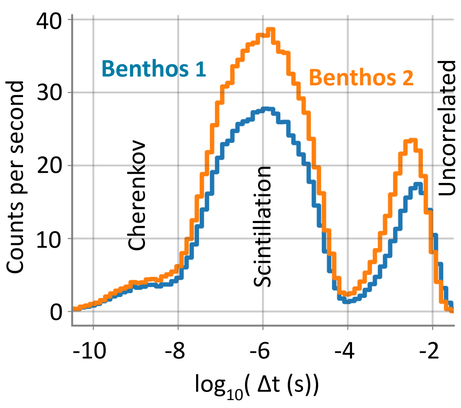
Temperature dependence of dark rate

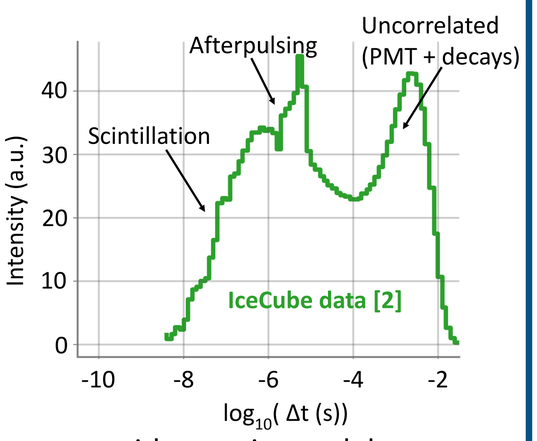




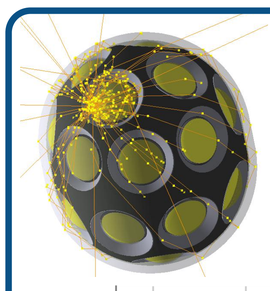
Simulated temperature dependence in good agreement with experimental data. Decreases with temperature due to change in yield.

Time between subsequent hits



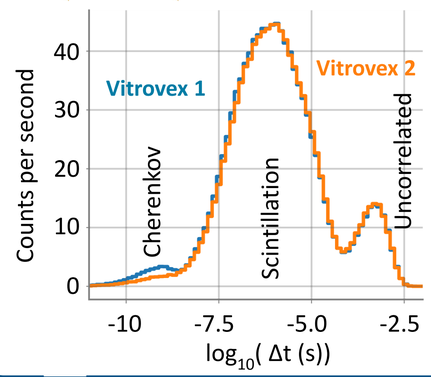


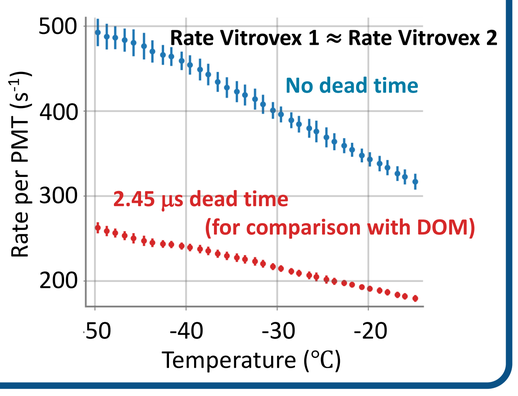
Shape of simulated Δt distribution agrees with experimental data. Cherenkov peak not measurable due to PMT time resolution.



Dark rates in multi-PMT module (mDOM)

- Baseline module for IceCube upgrade
- Vitrovex default vessel glass
- About 400 s^{-1} per PMT expected from radioactive decays in pressure vessel @-30°C





References

(1) M. G. Aartsen et al. (IceCube Collaboration), JINST 12 (03), 2017

(2) N. Stanisha, Bachelor Thesis, Schreyer Honors College (2014)

Scan for more information in master thesis

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