The Wavelength-shifting Optical Module (WOM) for the IceCube Upgrade

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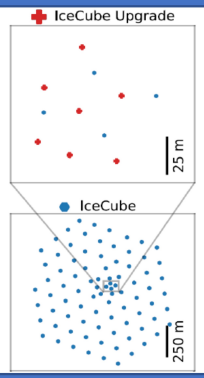
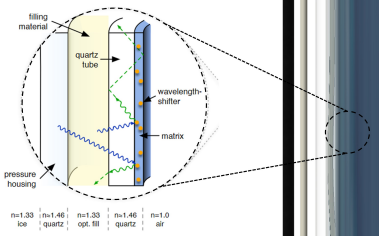
The IceCube Upgrade

- First extension of IceCube detector since completion in 2010
- Planned for deployment 2022/2023
- Deployment of over 700 additional modules in dense spacing
- Improve event reconstruction, lower energy threshold and more precise ice calibration
- In addition to the production modules (mDOMs and d-Eggs) there will be a number of R&D modules including 12 Wavelength-shifting Optical Module (WOMs)



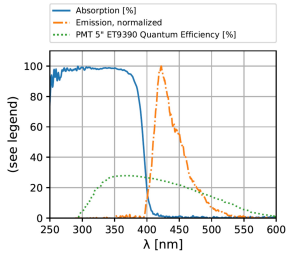
The Wavelength-shifting Optical Module (WOM)

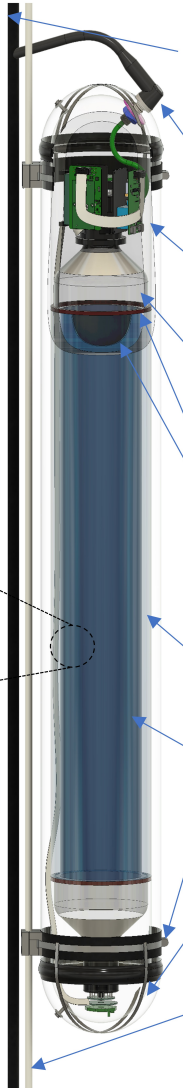
- Detector consists of transparent quartz tube, which is coated in wavelength-shifting paint
- Incident UV photons are absorbed, wavelength shifted and reemitted inside the tube
- Photons are guided to readout PMTs via total internal reflection



Features of the WOM or "why do we built this?"

- Idea: Shift photosensitive area to WLS coated tube to achieve large sensitive area with comparably small photocathode area
- UV sensitivity: Matched to Cherenkov emission
- Low noise due to small photocathode area: Ideal for supernova detection





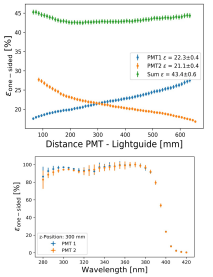
1. PMT ET9390

PMT choice based on:

- Reasonably large diameter to make best use of the available drill hole diameter
- Good efficiency at the edge of the photocathode as needed for coupling to the WLS tube
- Low thermionic noise to demonstrate good noise characteristics for supernova detection
- Gain>5 · 10^6 at safe voltages, for single photon detection using the selected DAQ
- Flat cathode surface to ease gluing of the tube

2. Wavelength-shifting tube

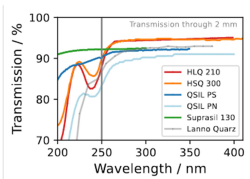
- Wavelength-shifting tube described in terms of efficiency ϵ (probability of a photon incident on tube is absorbed, reemitted and guided to the read out PMTs)
- ϵ is function of the position of the light entry point on tube in cylindrical coordinates ϕ and z and incident lights wavelength λ



3. Quartz Vessel

Pressure Vessel:

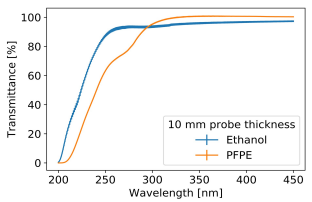
- Low noise from impurities in the order of 100 Hz for a 19 kg pressure vessel
- Good transmission between 250 and 400 nm



4. Filling material

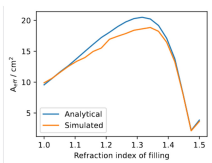
Filling Material choice:

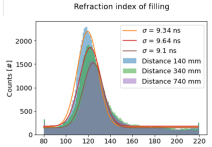
- Optical transparency
- Refractive index around n = 1.30
- Chemical interness
- PFPE as optimal choice



WOM properties

- Determined effective area of the WOM to be approximately 19 cm^2
- High sensitivity between 280 and 400 nm
- Module noise is dominated purely by PMT thermionic noise contribution. Quartz vessel contributes around 100 Hz
- Timing resolution dominated by WLS tube, ~10 ns at a fixed position





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