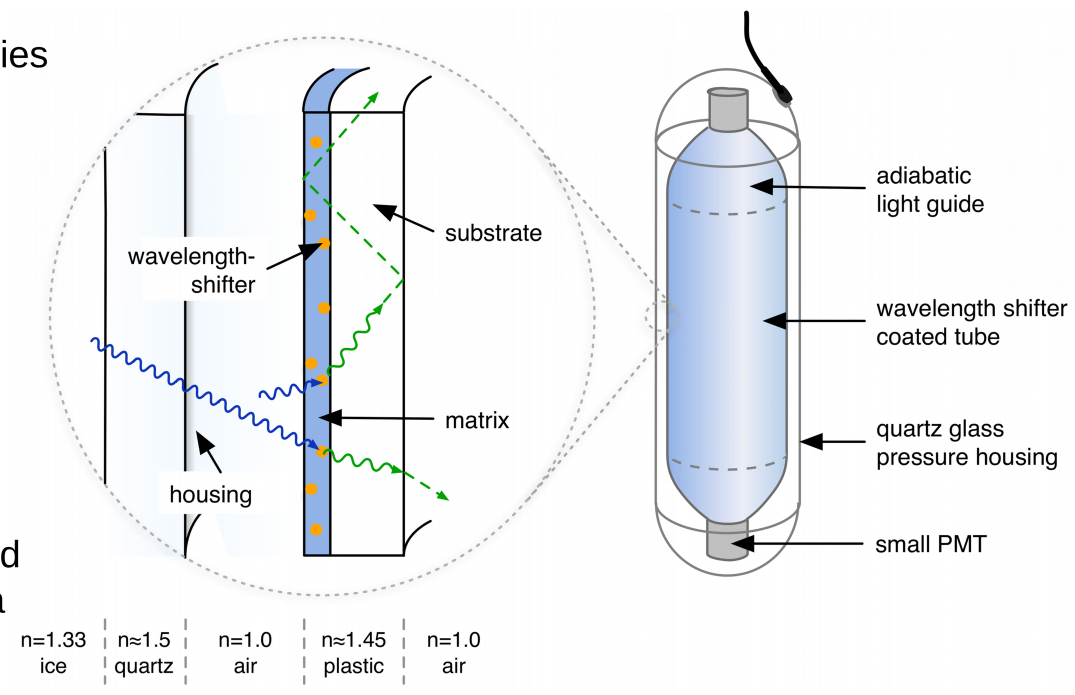
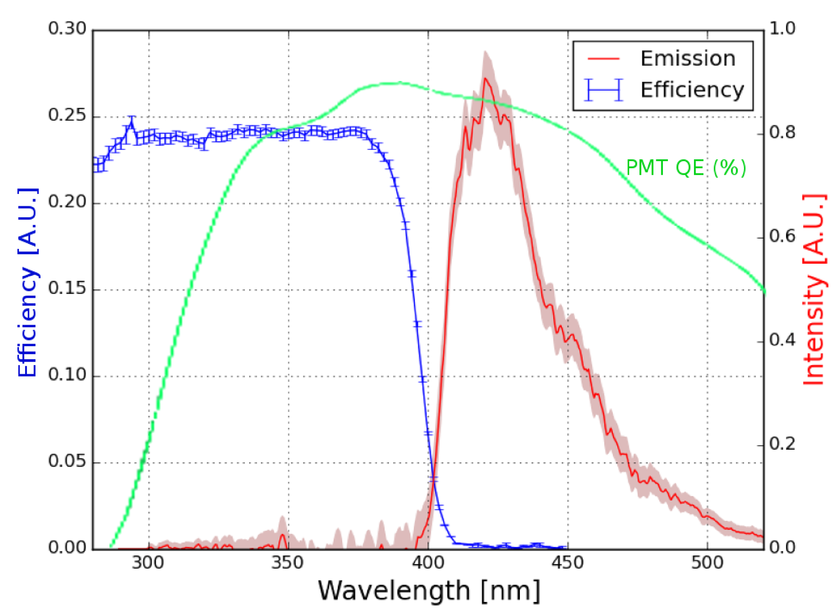
The Wavelength-shifting Optical Module (WOM)

Introduction

- One of the most important properties for Neutrino-detectors: signal-to-noise ratio.
- Bigger PMT → bigger photo-sensitive area
  BUT also bigger dark noise
  → SNR mostly unchanged
- The WOM employs a passive, wavelength-shifter (WLS) coated surface, total internal reflection and small PMTs → large effective area with low dark noise
- UV-transparent housing (quartz) + transparent tube coated with WLS.
- UV light is absorbed by the WLS and re-emitted isotropically.
- 74.5% of the re-emitted photons are trapped by total internal reflection.
- Light is detected by small PMTs at tube ends
- Optionally: concentrated light on even smaller PMTs with adiabatic light guides (ALG)
- Ideal for Cherenkov-detectors due to UV-sensitivity



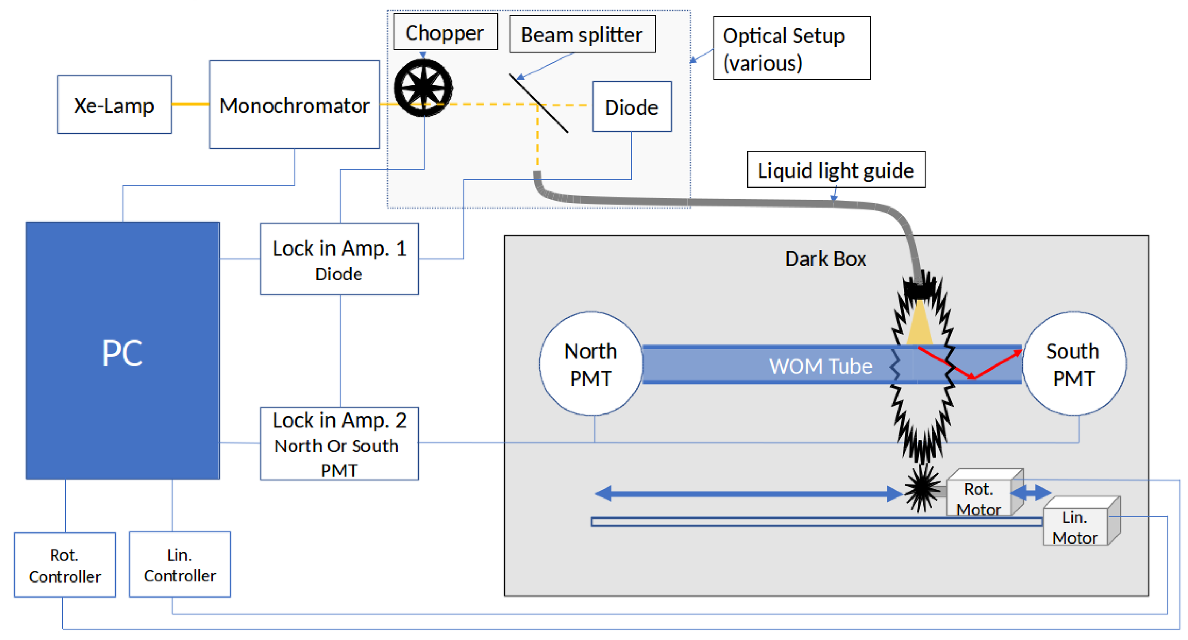
Schematic drawing of the WOM



Absorption and emission spectrum of the WLS and quantum-efficiency of the PMTs

Testing setup

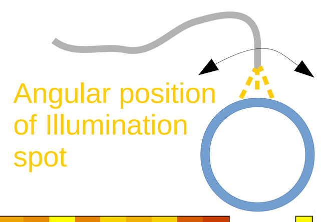
Test-setup schematic

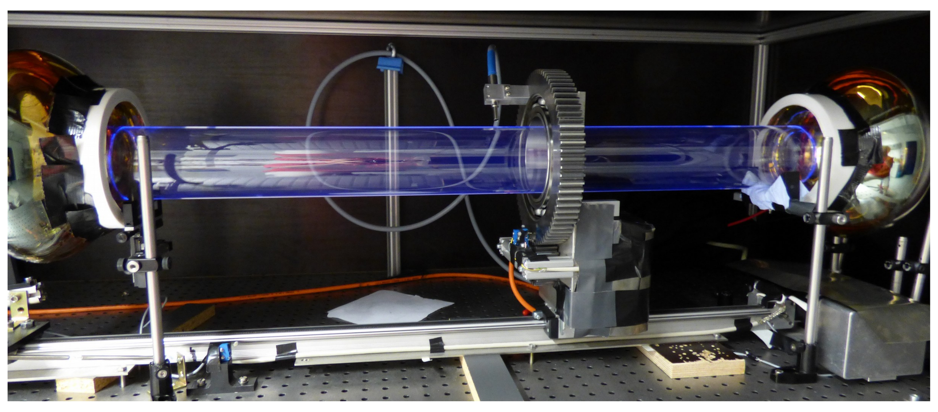


Task:
Characterize WLS coating and ensure uniformity of light-guiding efficiency for all tubes.

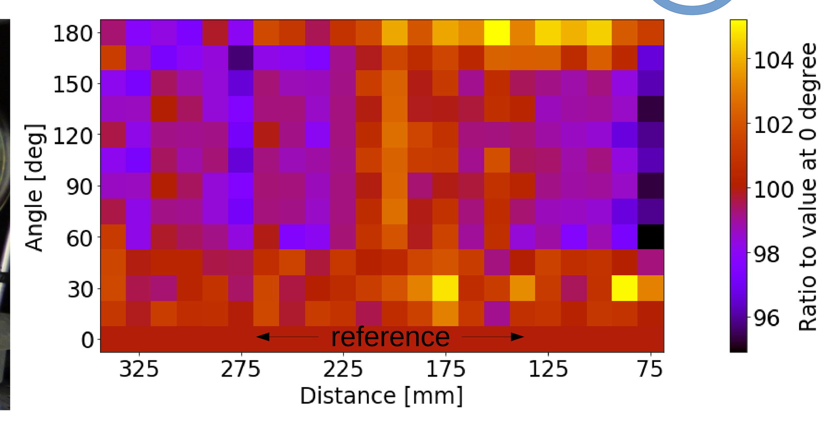
Solution:
- Orbital stage on a linear stage to guide an optical fiber along and around the tube.
- Fiber is connected mono-chromator and a Xe-lamp.
- Tube efficiency can be measured for all wavelengths and all illumination positions.

Definition:
Efficiency *= (#detected / #injected) photons, depends on WLS efficiency, trapping ratio, light guiding efficiency for the emitted light.*



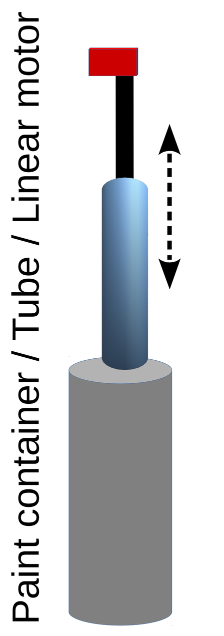


A photo of the Mainz WOM tester
Allows semi-automatic scans of coating uniformity. Second system using 3 small PMTs is at DESY Zeuthen

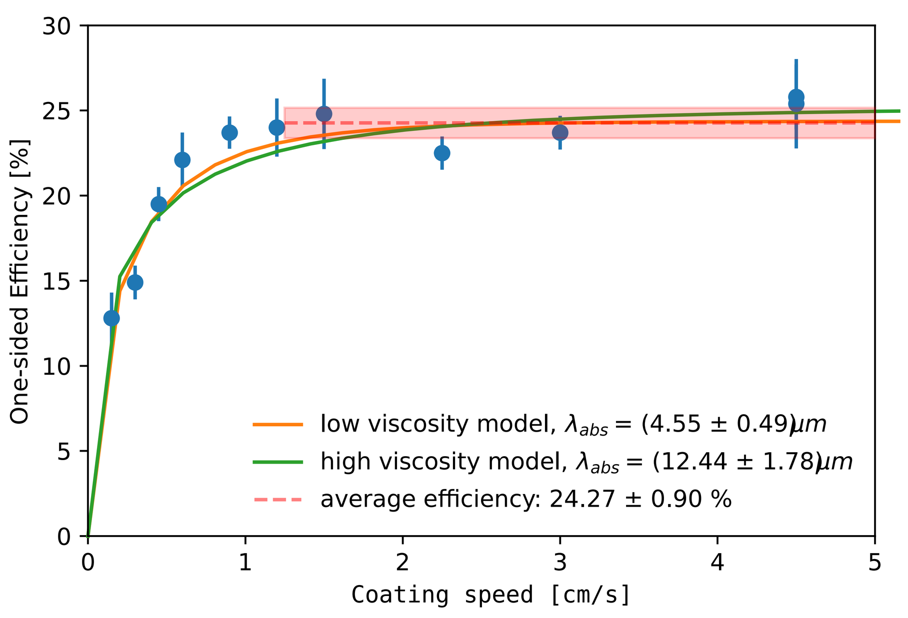


Sample result from a 2D scan. Relative PMT signal variation relative to signal at 0° over angular position.Incident wavelength λ=375 nm. Variation is smaller than ±5%

Building the WOM

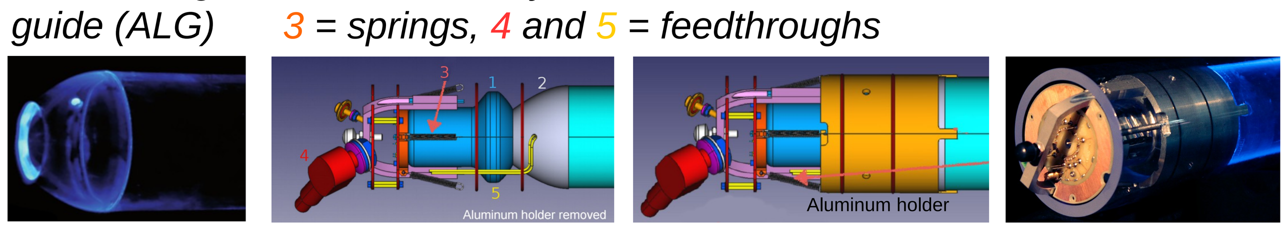


- A transparent tube is dipped in WLS paint and withdrawn at a controlled speed.
- The coated tube is connected to a PMT via a holding structure
  - Optionally via an ALG
- The entire assembly is housed in a quartz vessel with a feedthrough for power and signal cables
- Coating thickness depends on speed



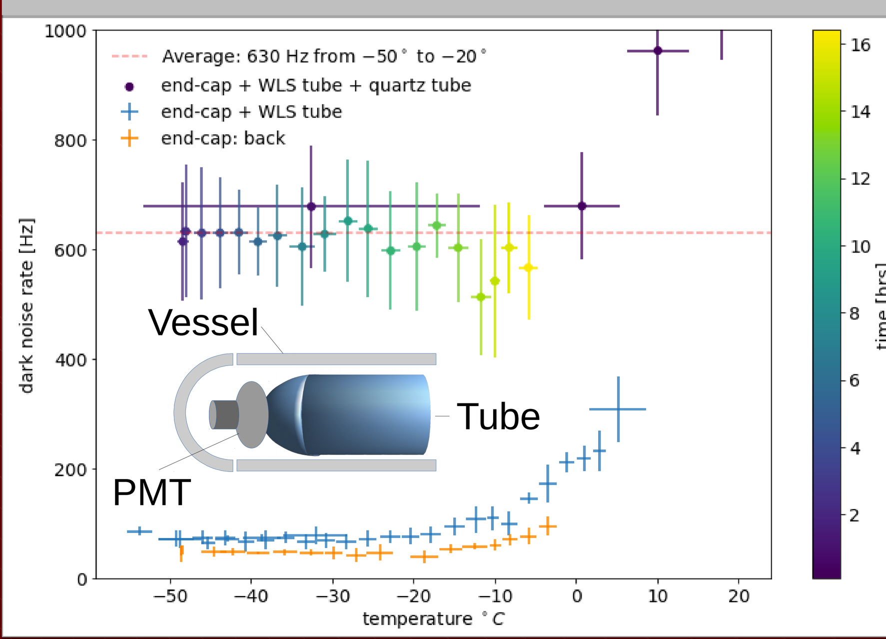
Performance vs. Coating speed on quartz-tubes. High reproducibility and high total efficiency (up to 24.3% per side)

Adiabatic light guide (ALG) *WOM assembly: 1 = PMT, 2 = ALG, 3 = springs, 4 and 5 = feedthroughs*



WOM prototype inside quartz vessel

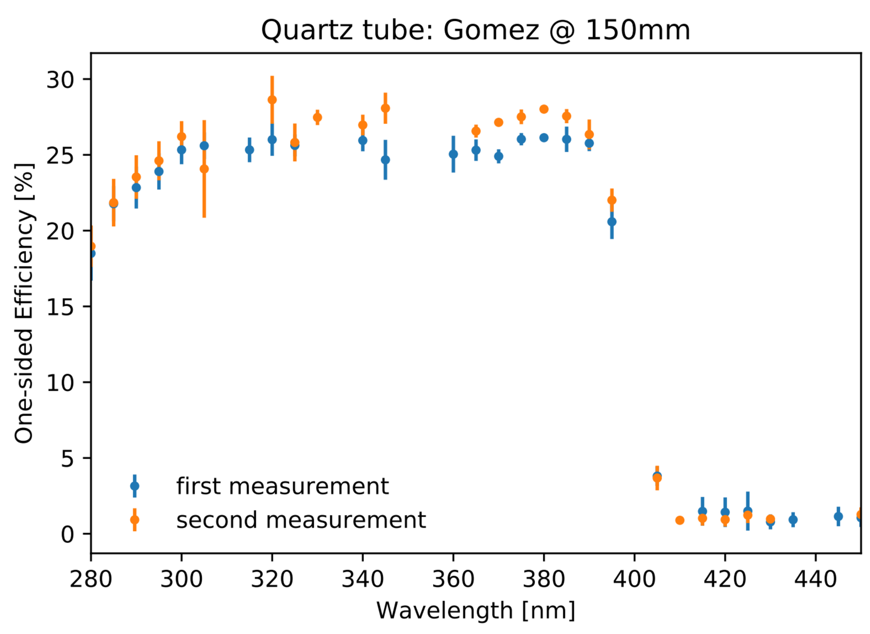
A dark noise challenge



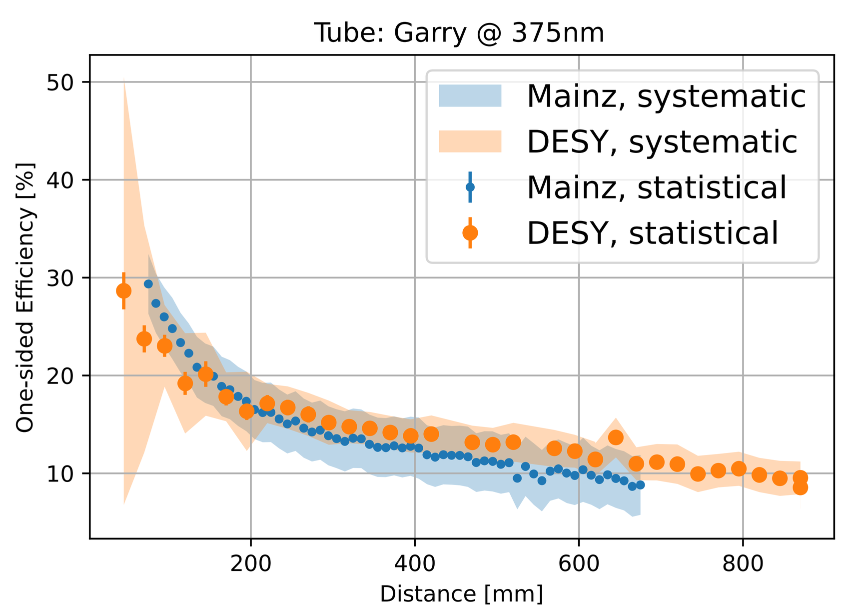
Dark noise measured inside a Faraday cage in a climate chamber (-50° to +20°C)

Dark noise of PMT: 30-50 Hz
...with ALG and WLS tube added: 70 Hz
...with quartz pressure vessel: 630 Hz!
BUT: this quartz contains ~150 ppm ^{238}U
→ cleaner quartz has been found (from Heraeus and Raesch)
→ produce vessel from clean, low activity quartz (HSQ300, SUP310 or RQ200)
→ expected new vessel contribution <10 Hz
→ expected total dark noise <80 Hz

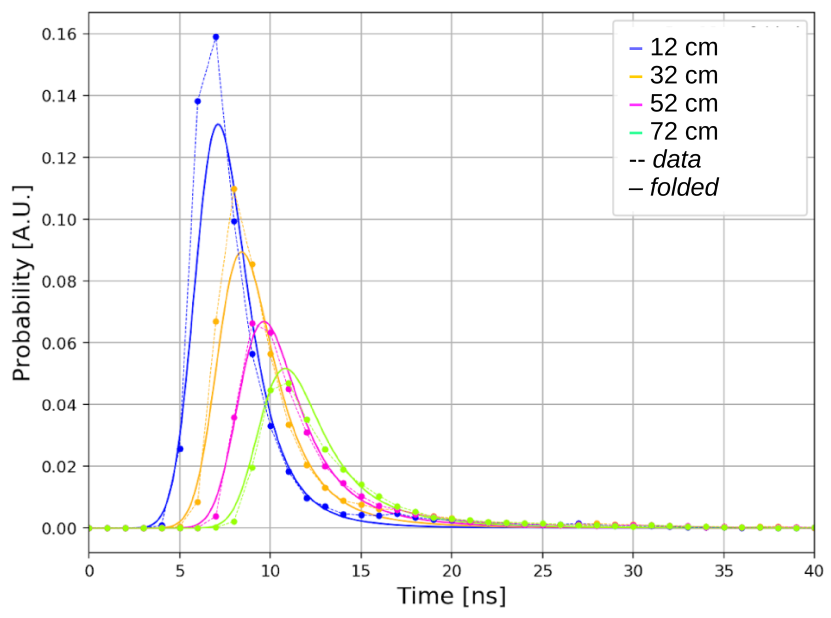
Performance



Wavelength-scan, one-side-efficiency vs. injected wavelength, illumination 150 away from tube end. Above λ=400 nm the UV-light is not absorbed.

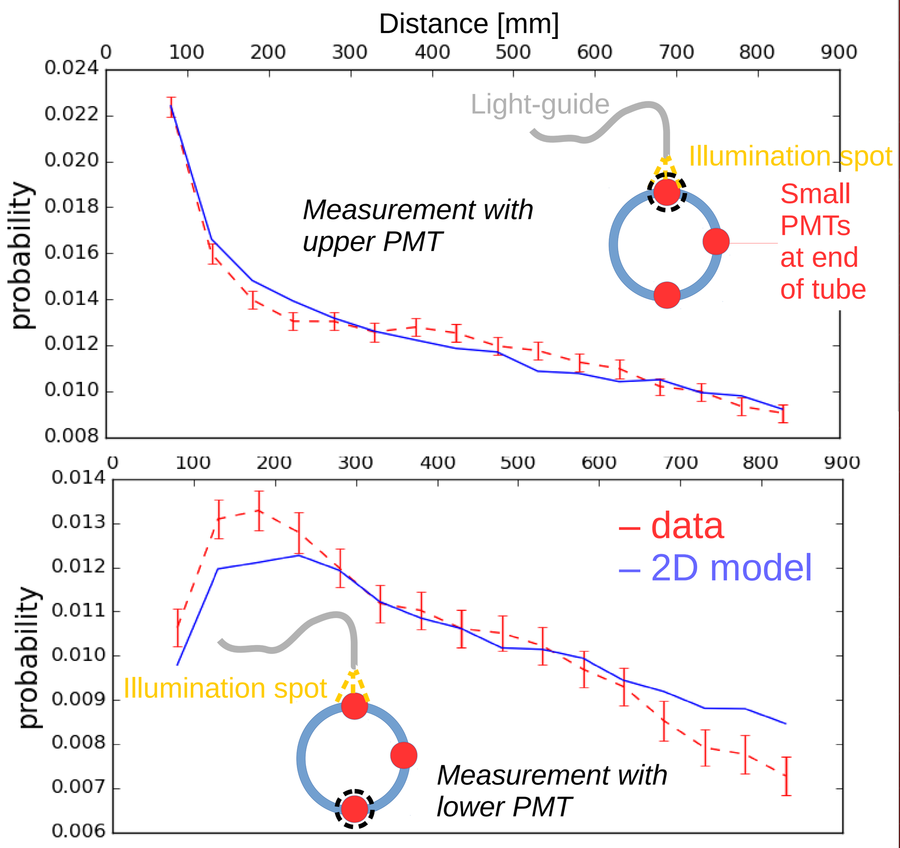


Distance-scan: total efficiency vs. Distance of illumination point from the tube end. Comparison of the two test setups. ***Average efficiency 38-43%*** *over 90 cm length.*



Timing: detection time of single-pe events using a picosecond UV-pulser, depending on illumination point distance from tube end.

Fit results: WLS-decay time = 1,35 ns
Photon-attenuation length: λ_{eff}= 320 cm

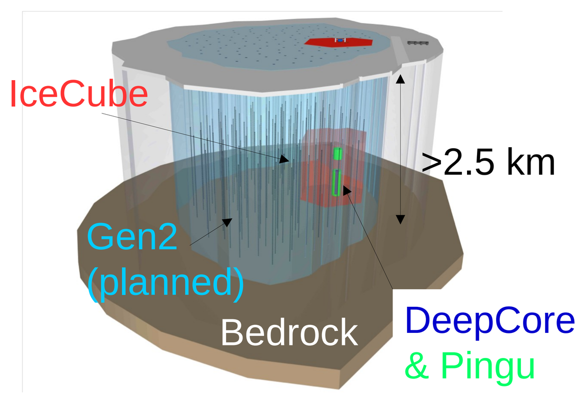


Measured light propagation fitted with a simplified 2D model (flattened tube mantle with periodic boundary conditions)

Summary

- **Prototype built**
- **41 ±1.7% avg. efficiency**
- **Improve SNR by factor >10 compared to PMT alone**
- **even higher with adiabatic light guide**

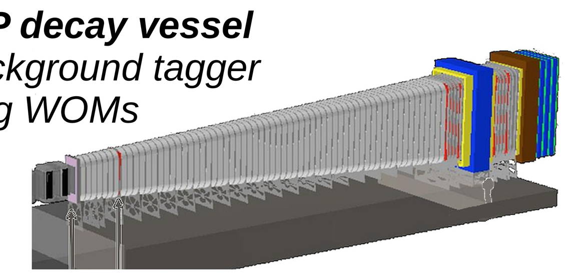
IceCube Gen2



Outlook

- **The WOM is ideal for experiments that aim to detect UV light with a high SNR**
- Initially developed for IceCube Gen2
- Focus: low noise and high effective area
- Main cost driver: quartz pressure vessel for 500 bar
  → only necessary in ice!
- A smaller, much cheaper WOM has been developed for **SHiP**, others may follow. → ***Hyper-K?***

SHiP decay vessel *+background tagger using WOMs*



PhD-position available! *

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