

Progress on the Development of a Wavelength-shifting Optical Module (WOM)

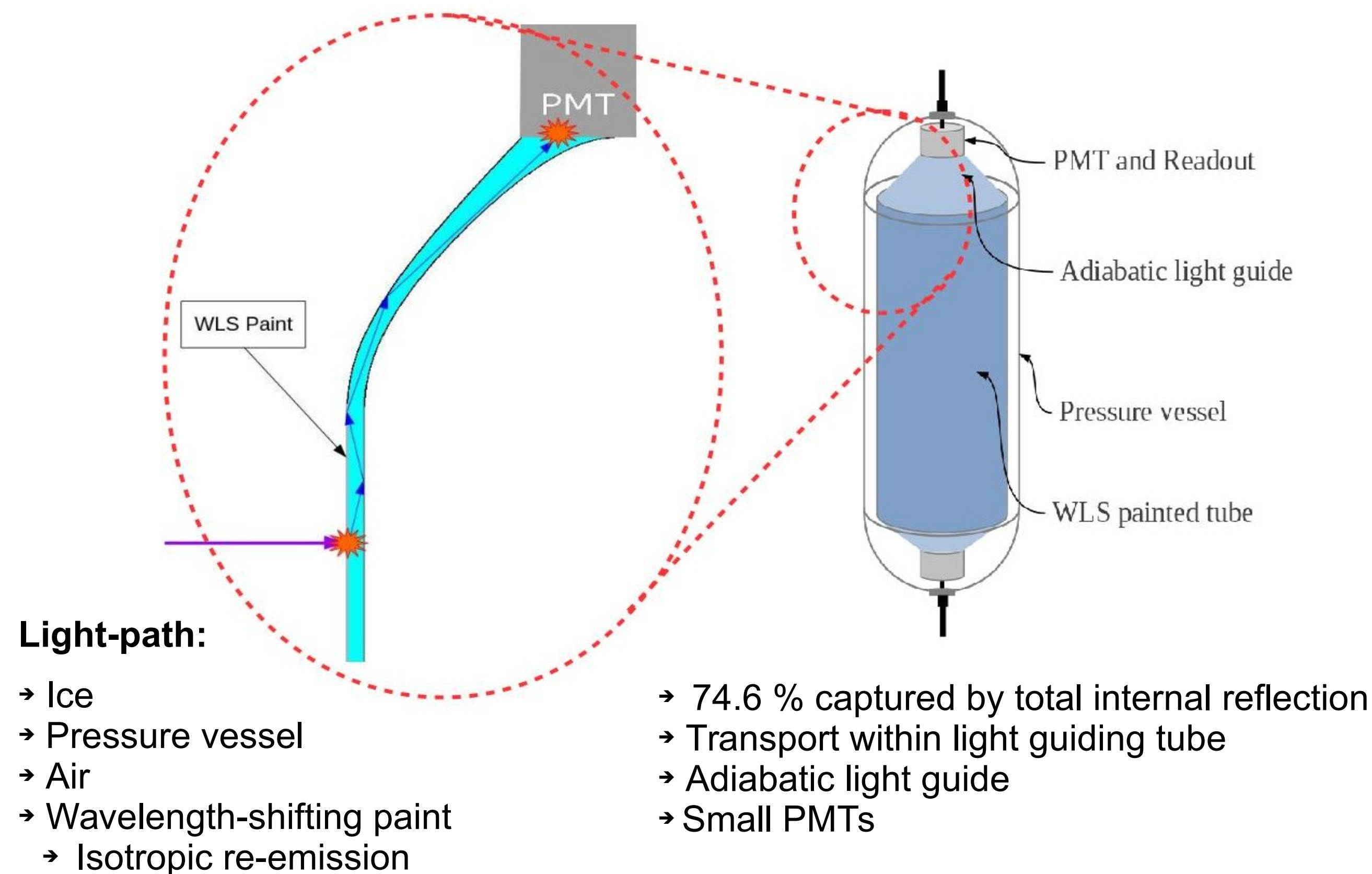
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Motivation

Devise an optical module for detection of Cherenkov light produced by secondary particles from neutrino interactions in ice with:

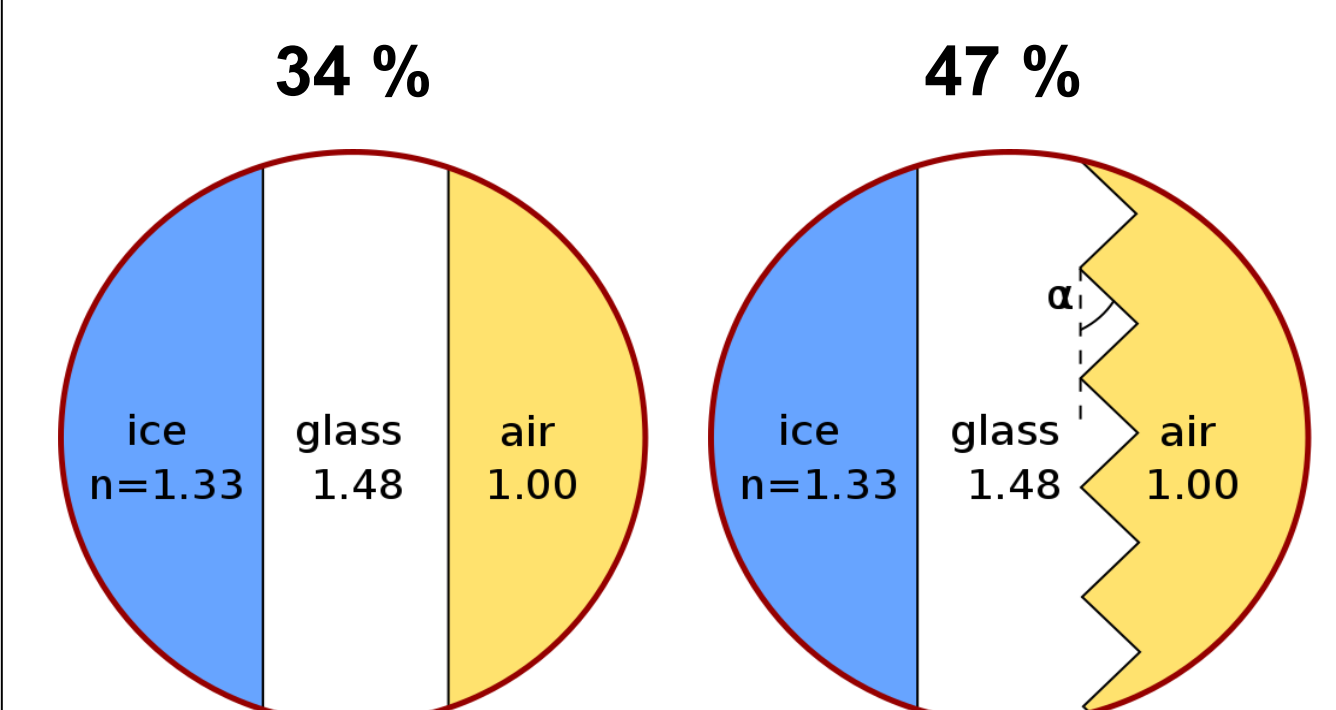
- Good UV-sensitivity (250-400 nm)
 - Cherenkov light ($\propto 1/\lambda^2$)
 - Ice very UV-transparent until 200 nm
- High efficiency
- Large detection area
- Low noise
 - Small PMT cathode area
- Low horizontal cross section
 - Smaller drill holes
- Low cost

Concept



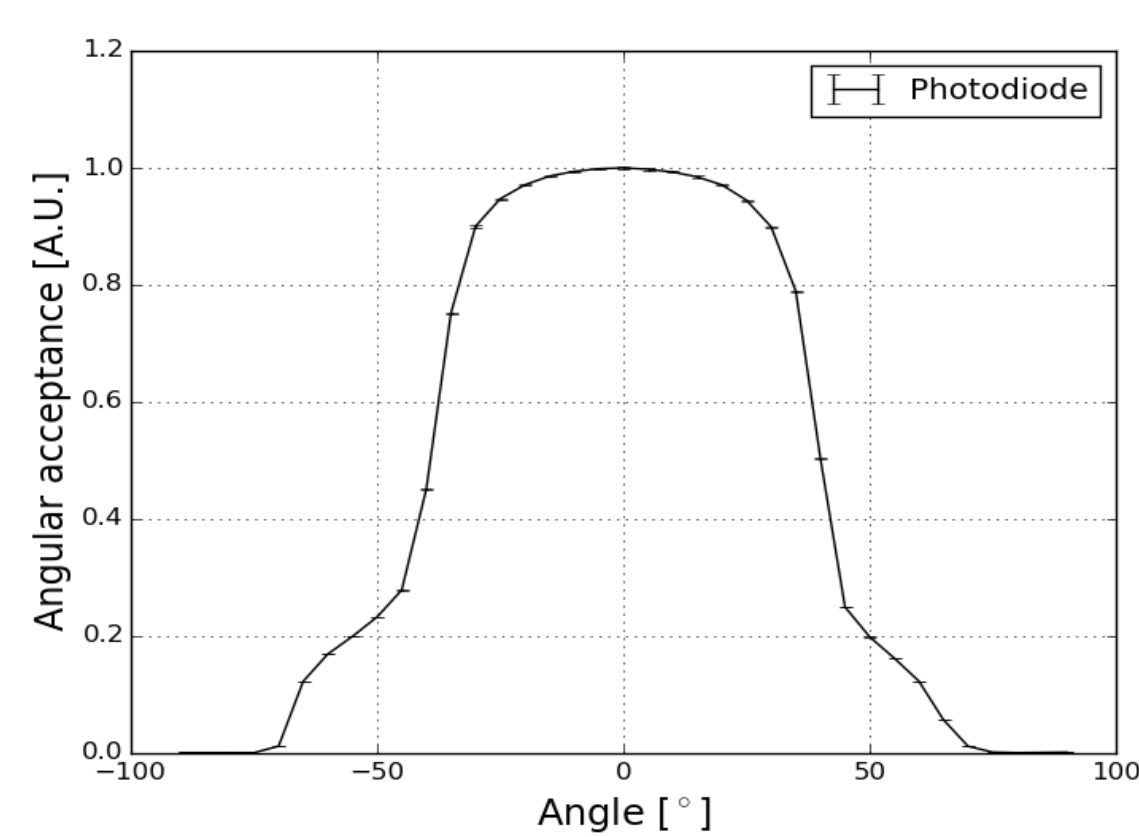
The Pressure Vessel

- 1.3 m long and 114 mm in diameter
- Made from UV transparent quartz glass
- First pressure test successful with pressures up to 5250 psi (362 bar)
- Structuring the inside of the pressure vessel with lenticular arrays may boost transmittance by up to 37 % (34%→47%)

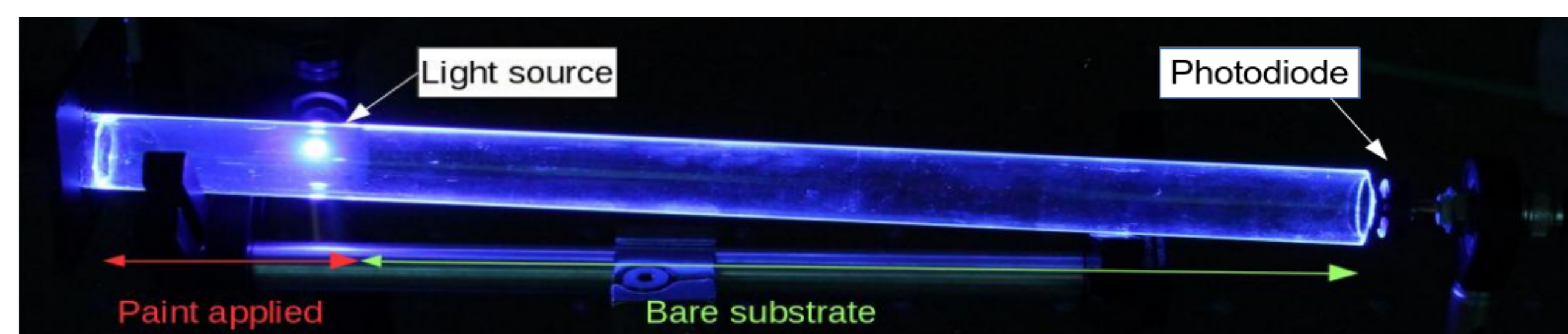


Theory & Reality

- Capture efficiency of 74.6 % is expected
- The loss length is currently about 80 cm
- ~23 % efficiency is currently measured with a photodiode setup after 30 cm
- Several potential causes are under study
 - Quantum efficiency of >90 % for the paint was determined
 - Low angular acceptance of the photodiode seems the most likely cause
- Measurements with PMTs are in progress

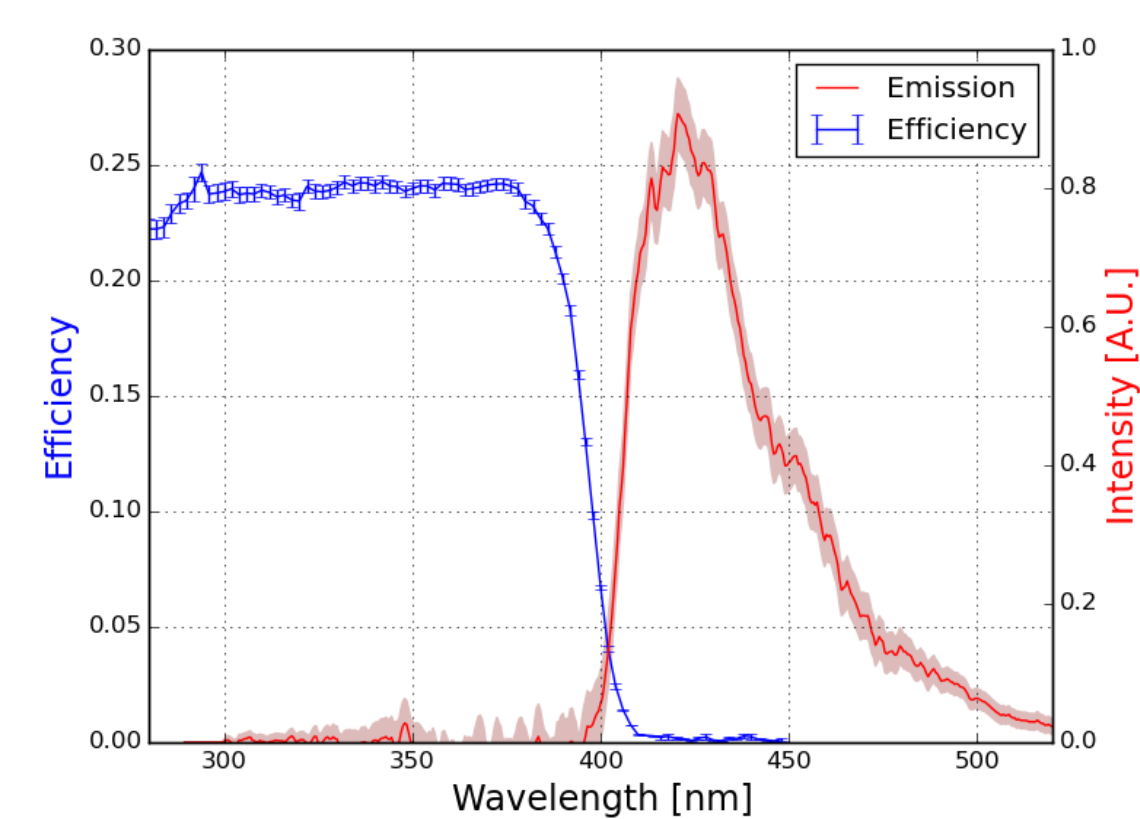


Efficiency



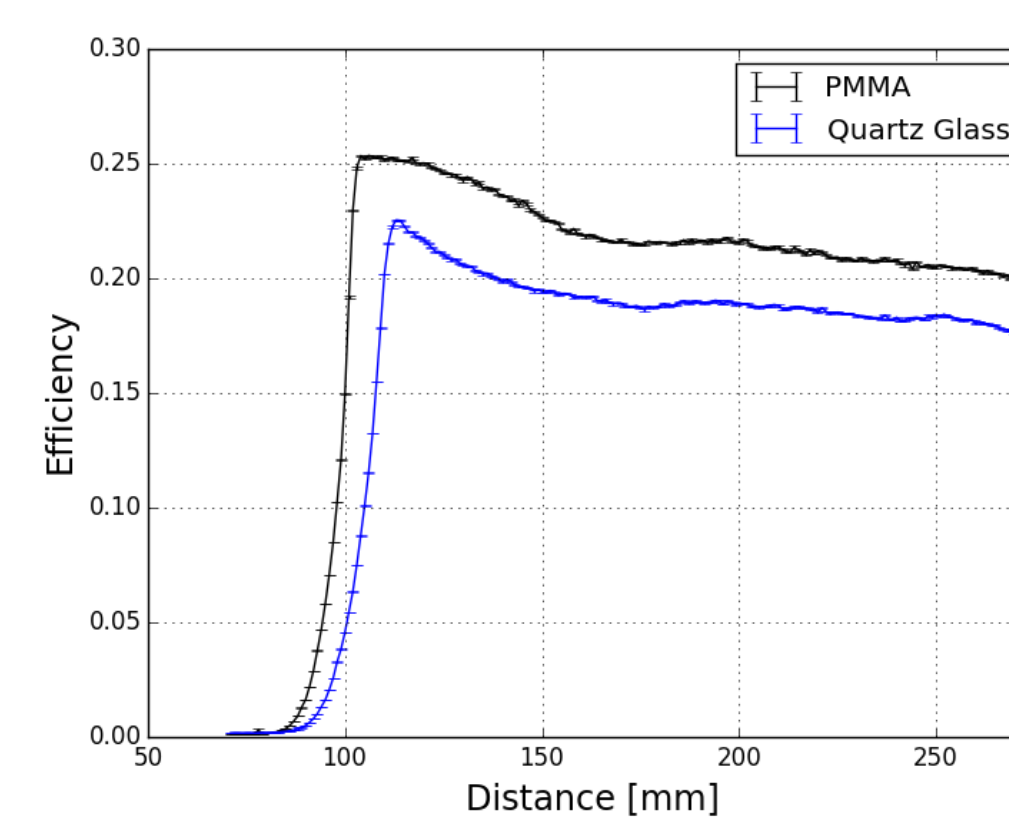
Wavelength-shifting Paint Development

- Custom made paint from Toluene, Paraloid B72, Bis-MSB and P-Terphenyl
- Same peak efficiency but broader; shorter absorption length
- Dip-coating process used for application



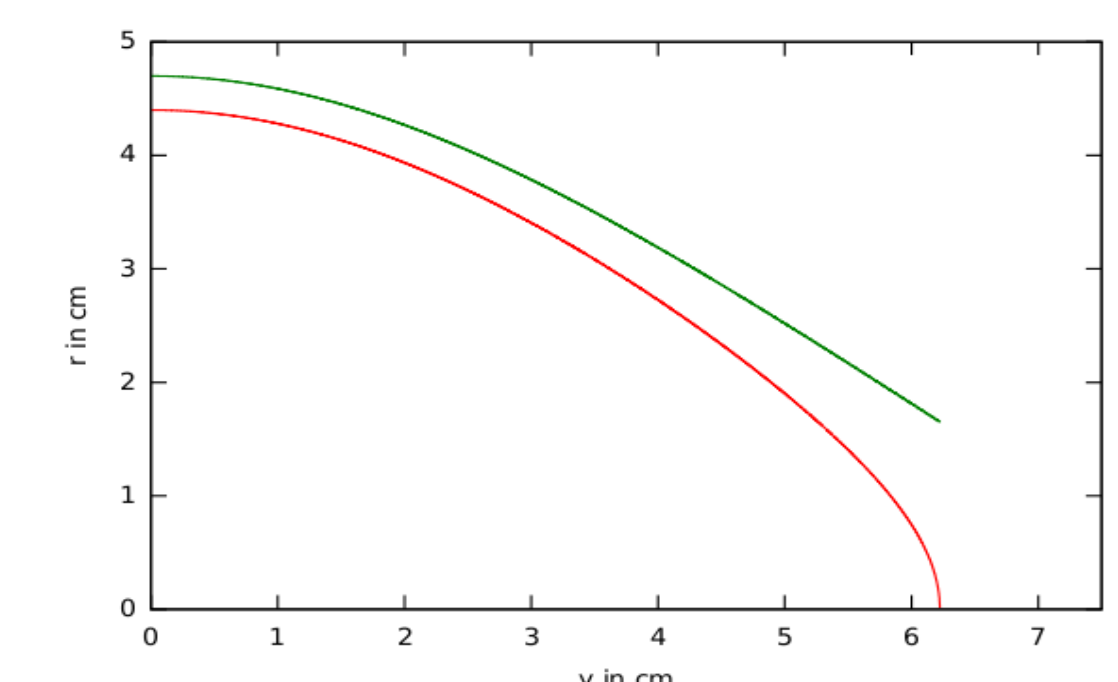
Substrate

- PMMA performed best in comparison
- Improving loss length by:
 - Cleaner materials
 - Reduction of vibrations during coating
- To limit the propagation losses, WLS tubes of 90 cm length are used for now



Adiabatic Light Guide

- Redirects light from the tube onto the PMT
- Ideal shape for lossless light transport was calculated

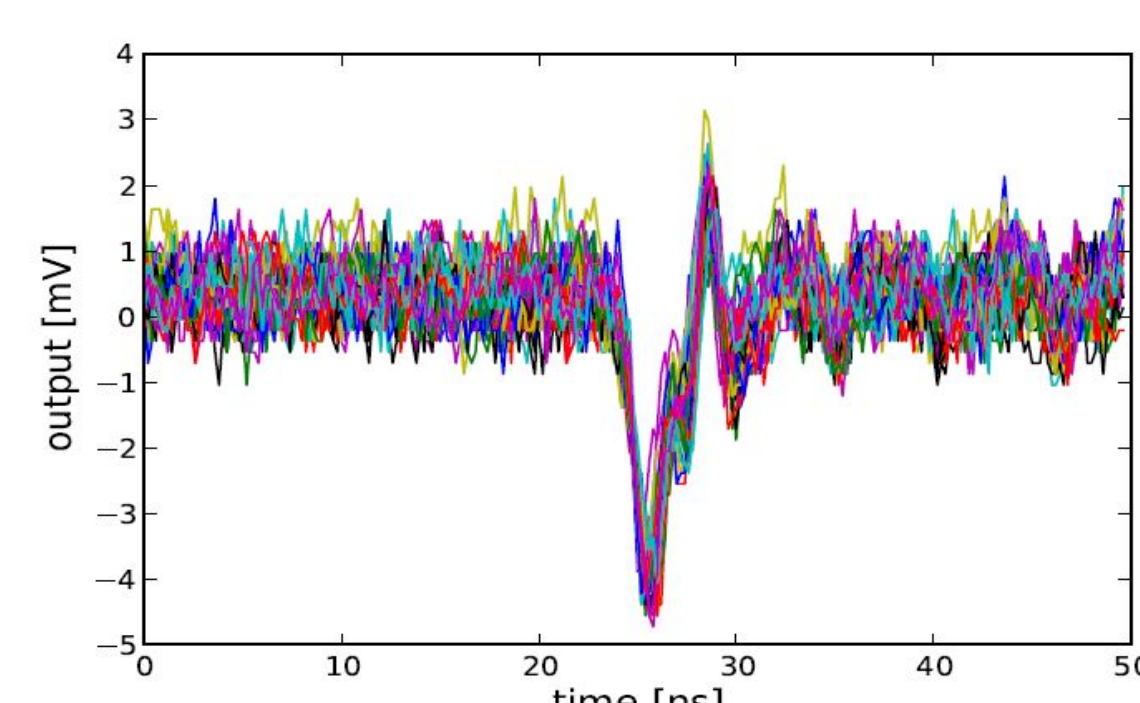
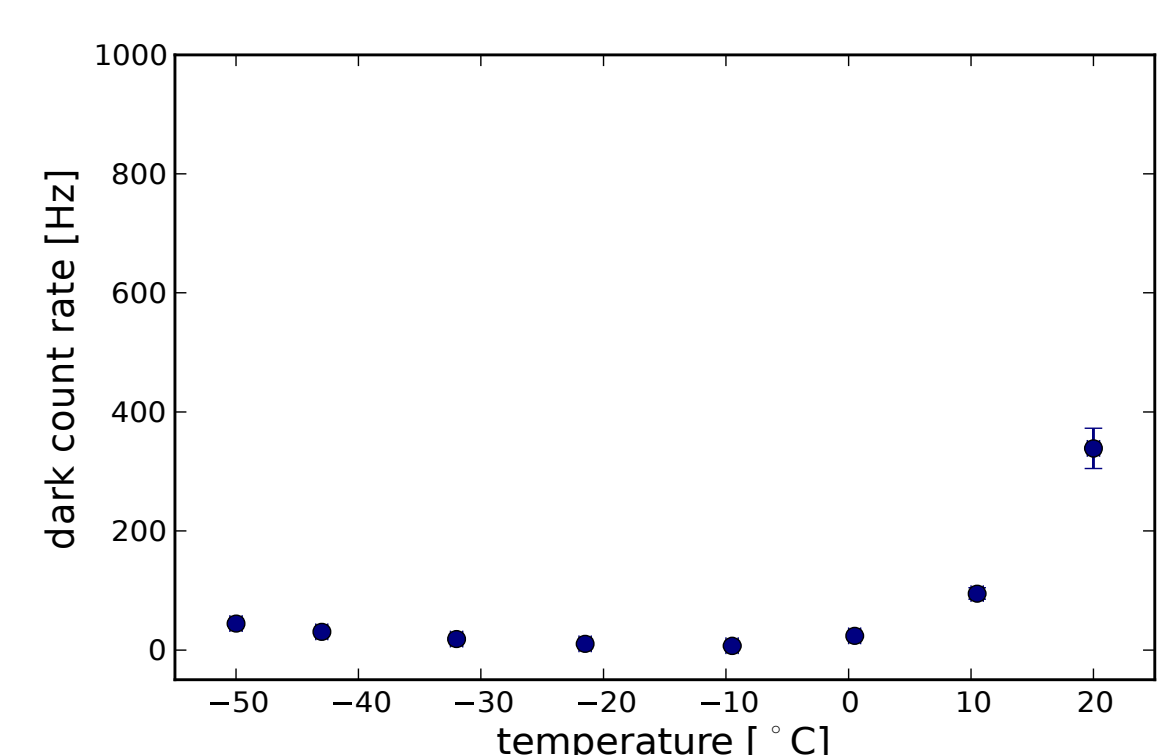


- Several prototypes with this shapes have been manufactured and will be tested soon



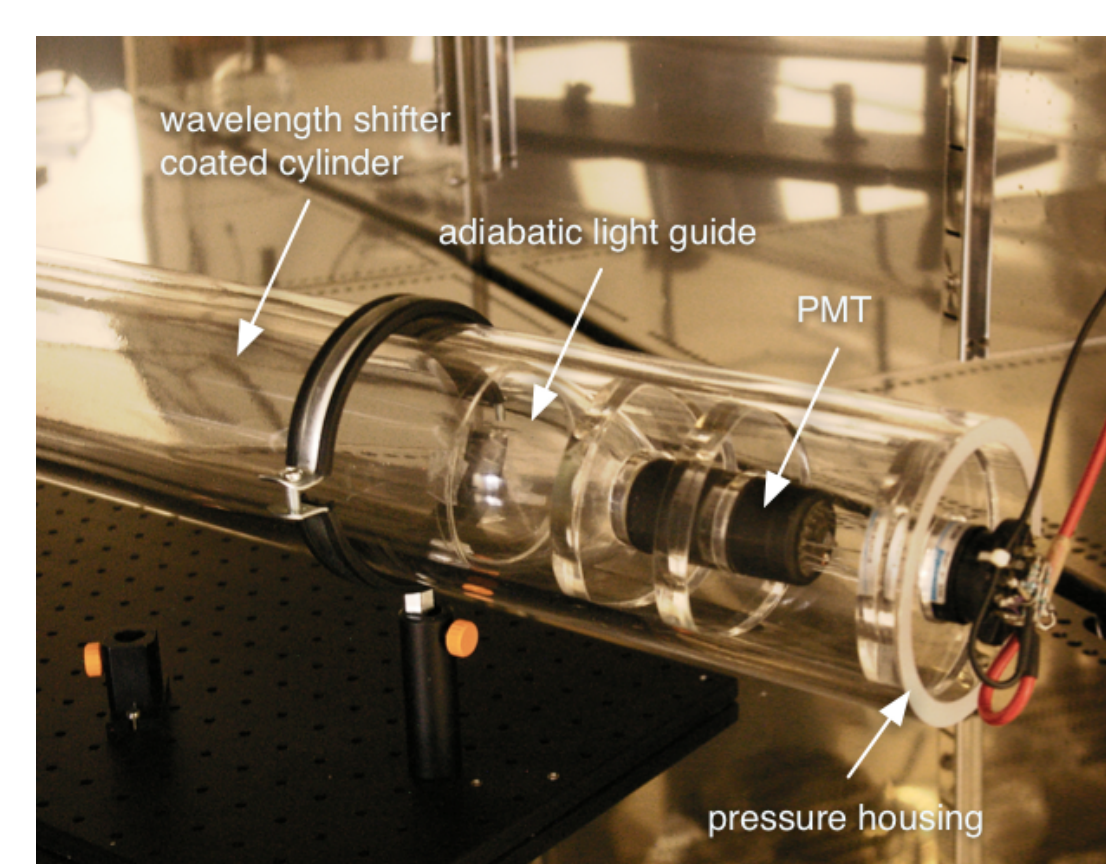
Electronics and Noise

- For initial tests the R11920-100 PMT from Hamamatsu was chosen. It has a 1.5" diameter, 40 % peak quantum efficiency and >94 % collection efficiency
- For the readout several FADCs, a 1 GHz oscilloscope and a prototype board for the IceCube-Gen2 optical modules were explored
- Low temperature noise rate measurements were taken in a dark box inside a climate chamber
- For IceCube-Gen2 relevant temperatures PMT dark count rates are between 11 and 19 s⁻¹
- We are looking into higher gain PMTs or suitable preamplifiers as well as customized readout systems



Conclusion and Outlook

- A high efficiency wavelength-shifting paint has been developed
- The paint shifts light from the range of 250-400 nm to >400 nm
- 23 % capture and transport efficiencies in the range with photodiodes
- The concept is flexible and can be adapted for other types of detectors like ShiP (arXiv:1504.04956)



- First PMT measurements indicate that our measurements technique might use improvement and the efficiency might be much higher
- An adiabatic light guide has been produced that acts as an adapter between WLS tube and small PMTs
- The noise rate of Hamamatsu R11920-100 PMTs has been investigated at low temperatures
- The quartz glass pressure vessel passed pressure testing
- Currently we are close to assembling a first prototype to obtain final values on the detection parameters
- First prototypes will be deployed with IceCube-Gen2