Improving the Light Absorption Probability in WOMs

2nd High-D Consortium Meeting

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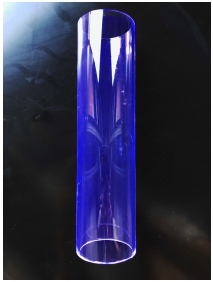
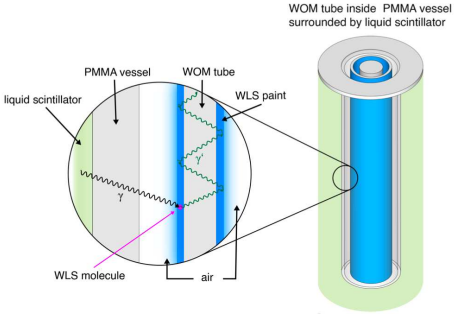
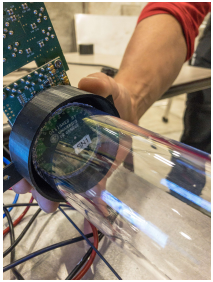
Working principle of a WOM

- Plastic PMMA tube coated on the outside with wavelength-shifting (WLS) paint
- Absorption of scintillation light and isotropic re-emission by WLS molecules
- Total internal reflection on plastic/ air boundary
- Light guided to silicon photomultipliers (SiPM)

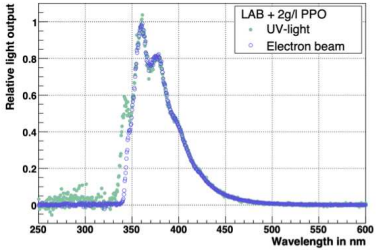




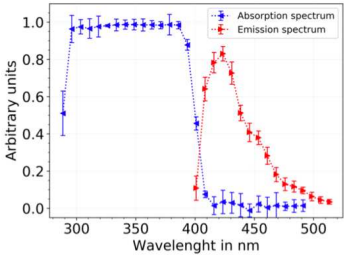


Wavelength-Shift from scintillation light to SiPM sensitivity

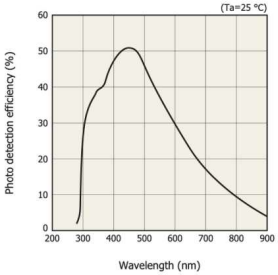
Liquid Scintillator Emission



Wavelength-shifter Bis-MSB



SiPM PDE



340 nm - 420 nm → 300 nm - 400 nm to 400 nm - 450 nm → 400 nm - 550 nm

Starting point: "Standard paint"[1]

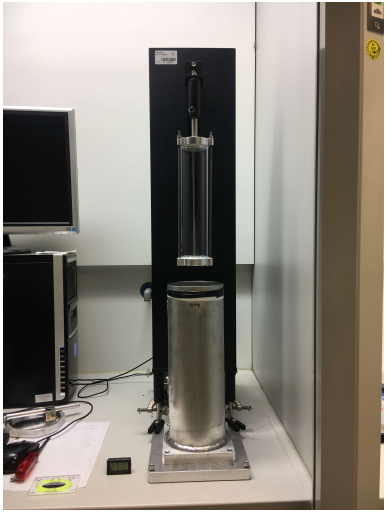
component	name	mass [g]
Solvent	Toluene	870 (1 liter)
Matrix	PEMA	250
WLS (deep UV)	p-Terphenyl	3.0
WLS (near UV)	Bis-MSB	1.5

Mix components on hot plate with magnetic stirrer

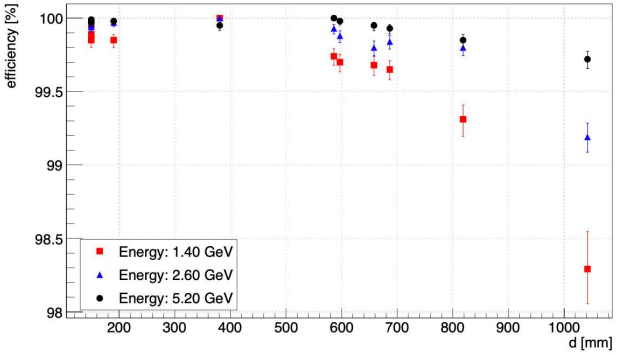
[1] (Developed by Benjamin Bastian-Querner and Dustin Hebecker for IceCube WOMs [1, 5])

Dip-coating setup

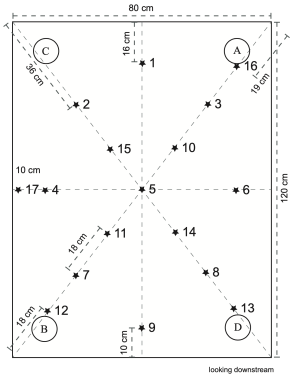
- Tubes coated only on the outside: Sealed by aluminium caps
- Commercial dip-coater
- Adjustable coating velocity and immersion time



Improvement of standard procedure needed



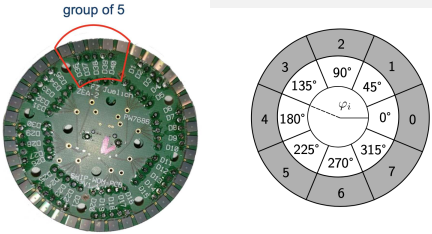
Detection efficiency of cell measured with e^- at DESY (2019) for different beam-to-WOM distances. Taken from [6].



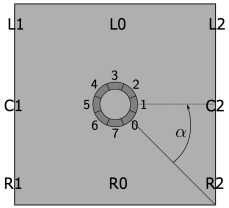
Beam positions on LS prototype cell. Taken from [3].

- 99.9% detection efficiency needed up to O(1m) beam-to-WOM distance
- Increase absorption probability of WOM

Motivation II - Directional information

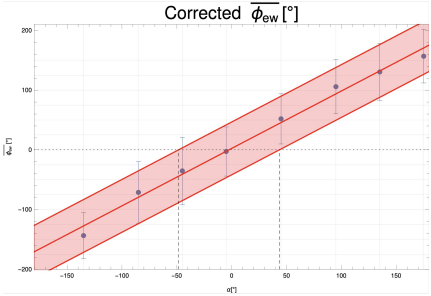


40 SiPM array PCB - 8 channels with 5 SiPMs each. Angle ϕ as measure for direction of light yield distribution.



Direction of primary photon α.

- Light-yield distribution over SiPM array potentially caries information about incoming primary scintillation photon direction
- One wants to guarantee photon absorption in the WLS where the photon hits the WOM the first time
- Currently studied by Andrea Ernst [4] and Alexander Vagts



Correlation between direction of incoming primary photon and light yield distribution in SiPM array. Red shading denotes average standard deviation of fits.

Coating parameters to change

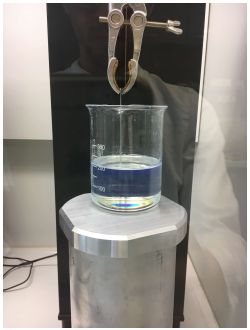
- **Increase concentration of WLS molecules** in paint
  - Problems with solubility
  - Maximum conc.: Bis-MSB about 1.2x (w.r.t. standard paint)
- **Increase thickness d of paint layer**
  - Evaporate toluene $\rightarrow$ increase PEMA concentration in paint $\rightarrow$ increase paint's viscosity η
  - Increase coating speed $v_{coating}$ (at withdrawal)
  - Double coating

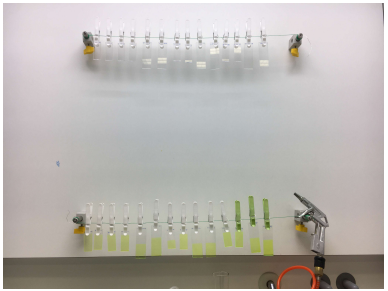
$$d \propto \sqrt{\frac{v_{coating} \cdot \eta}{\rho \cdot g}} \qquad (1)$$

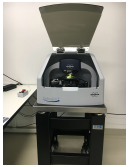
thickness d, coating speed $v_{coating}$, paint viscosity η, paint density ρ and gravitational acceleration g [2]

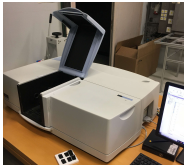
Investigating coating parameters

- Dip-coating slides (Glass, extruded PMMA, casted PMMA)
- Layer thickness with a profilometer: Only glass
- Transmission spectra 250 nm - 600 nm (measured by Andrew Conaboy)

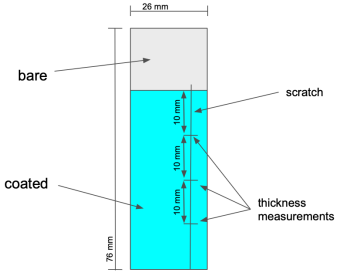


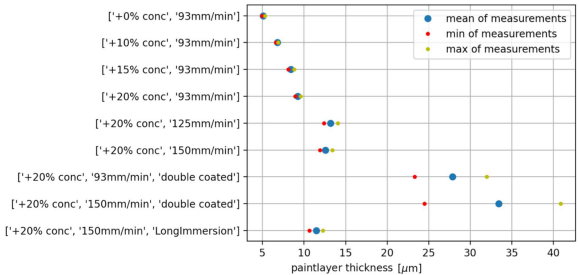






Thickness measurements on glass slides

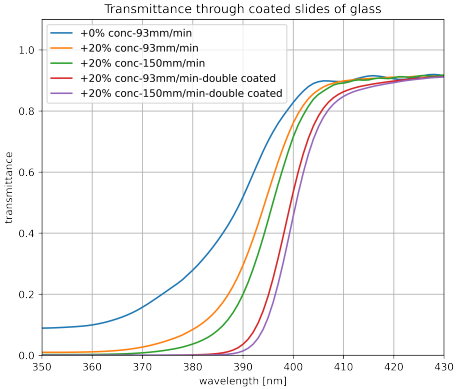




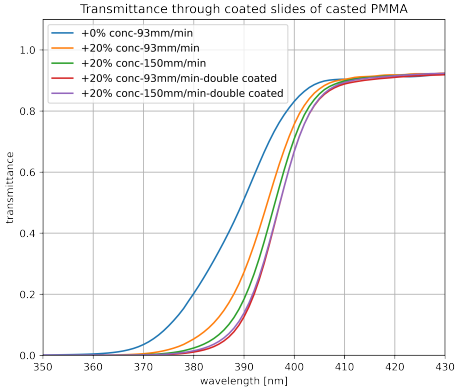
- Thickness increases with PEMA concentration, coating speed and repetitions
- Increase of more than factor 5
- Longer immersion during second coating dissolves first coating layer

Transmission measurements

Significant increase in absorption due to larger thickness.



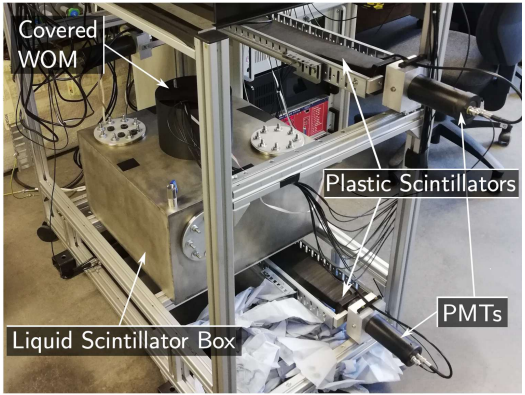
(a) Transmission through layer on glass.



(b) Transmission through layer on casted PMMA

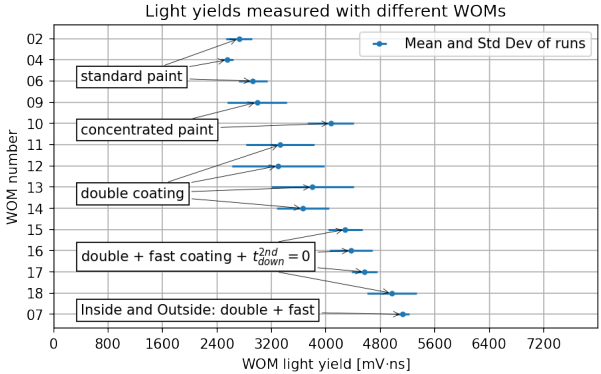
Prototype liquid scintillator cell at HU Berlin

- Test performance of new WOMs
- Measurement of cosmic muons
- LAB + PPO liquid scintillator
- Equipped with WOM coupled to SiPM array
- Coincidence trigger from 4 PMTs coupled to 2 plastic scintillators
- Read-out by *Wavecatcher* digitizer



Borrowed from [4]

Light yields of coated WOMs



- Light-yield measured by SiPM-array on WOM in test-box
- Increase of up to 100 % compared to the standard procedure

Summary

- Beneficial parameters for high absorption:
  - High coating velocity
  - Short immersion during 2nd coating
  - Multiple coatings
  - High viscosity
- New coating parameters increase light yield of WOMs substantially!

Thank you for listening!

References

- Master's theses: Jan Zimmermann, Benjamin Bastian, Dustin Hebecker, Maximillian Ehlert, Julian Schliwinski
- WOM workshop 2021: https://indico.cern.ch/event/1031683/
- (WOM workshop 2019)
- http://dx.doi.org/10.1140/epjd/e2010-00004-1
- https://arxiv.org/pdf/2009.06003.pdf