Wavelength-shifting Optical Module (WOM)

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HAP Workshop: Advanced Technologies | Mainz | 2016-02-02

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JOHANNES GUTENBERG UNIVERSITÄT MAINZ

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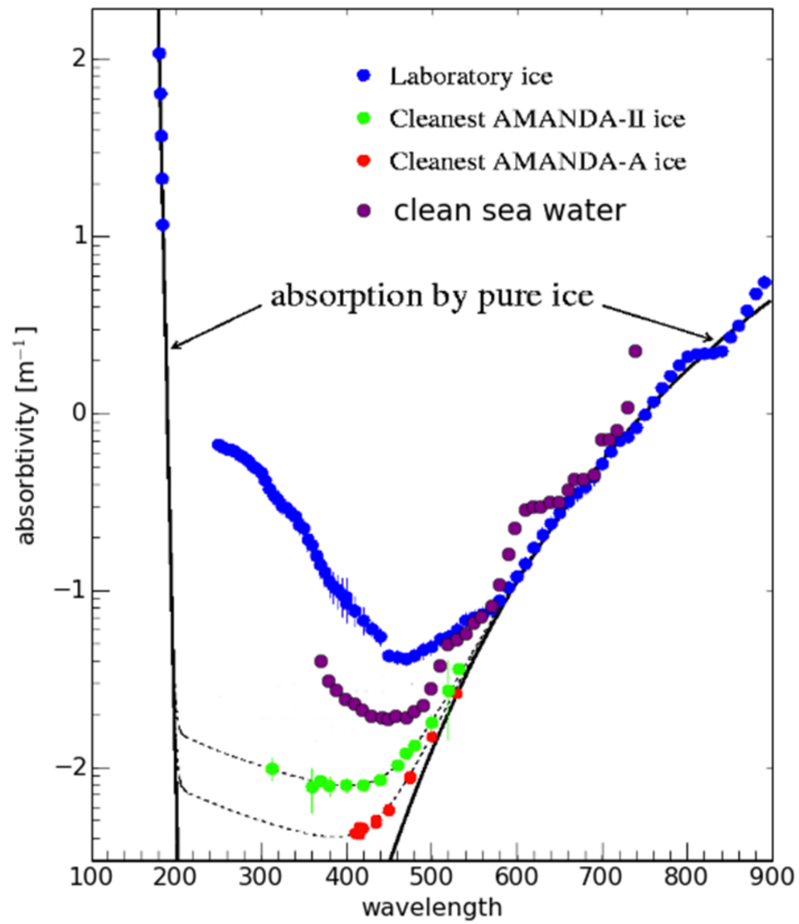
Cherenkov light

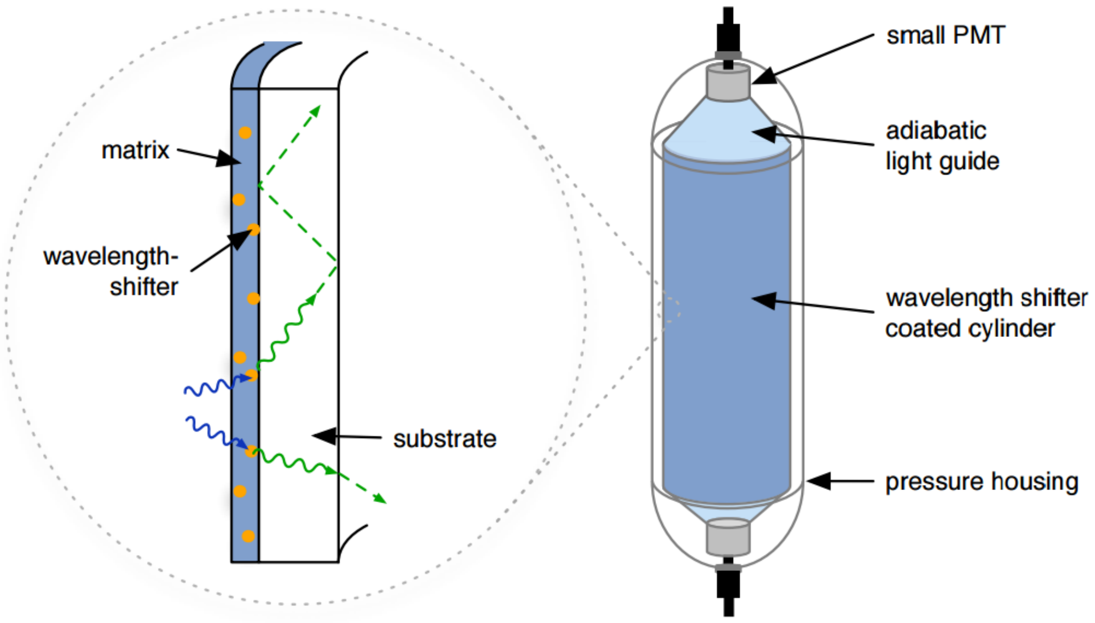
- Increase the energy resolution decreasing the energy threshold
- Cherenkov light is $\propto 1/\lambda^2$
  - More photon in the UV region

$$\frac{d^2N}{dx d\lambda} = \frac{2\pi z^2}{\lambda^2} \alpha \sin^2\theta$$

- absorption coefficient:
  - Low in the wavelength range of 250 – 400 nm
- maximize the collection area minimizing the dark count rate



Wavelength-shifting Optical Module concept



Setup:

- Pressure vessel (Ø 114 mm × 1,3 m)
- Coaxial WLS tube (Ø 90 mm × 90 cm)

Main advantages of the WOM:

- High efficiency in the UV range
- Large sensitive area
- Passive components as collectors and concentrators only
  - Reduce the noise to ≈ 10 Hz (Icecube DOMs ≈ 500 Hz)

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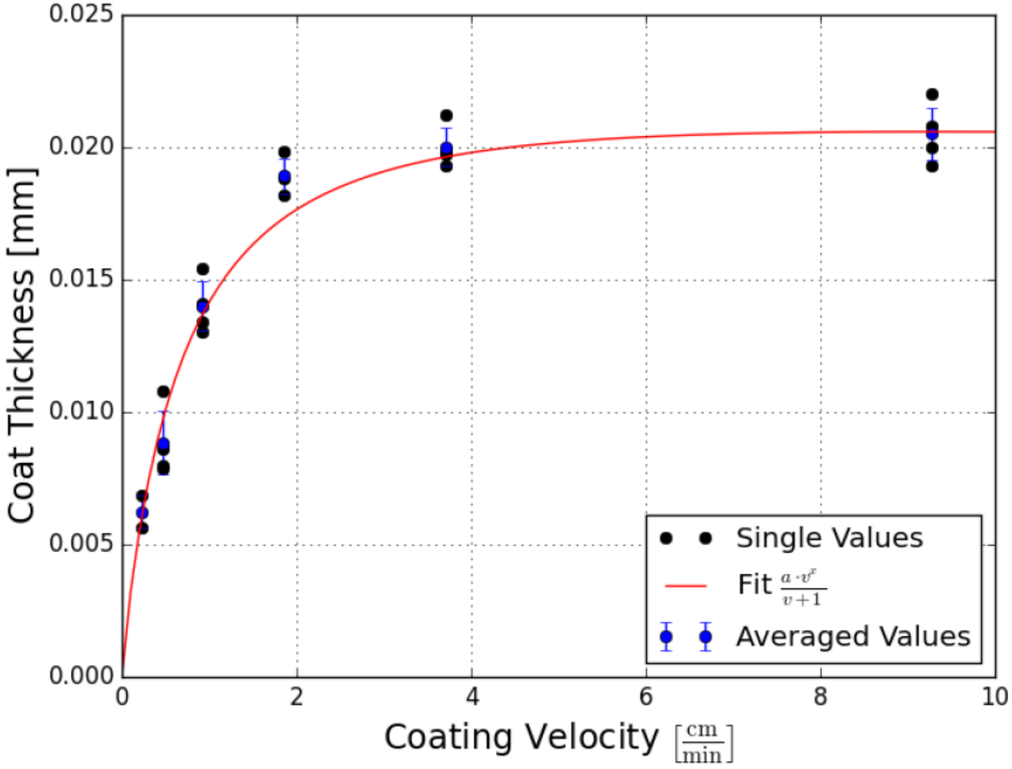
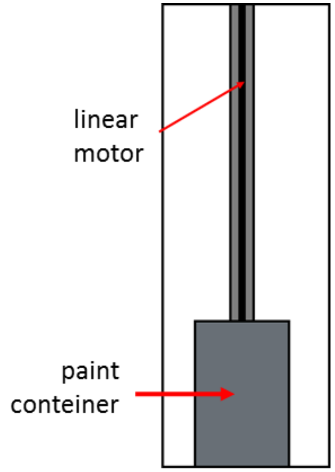
Paint plot

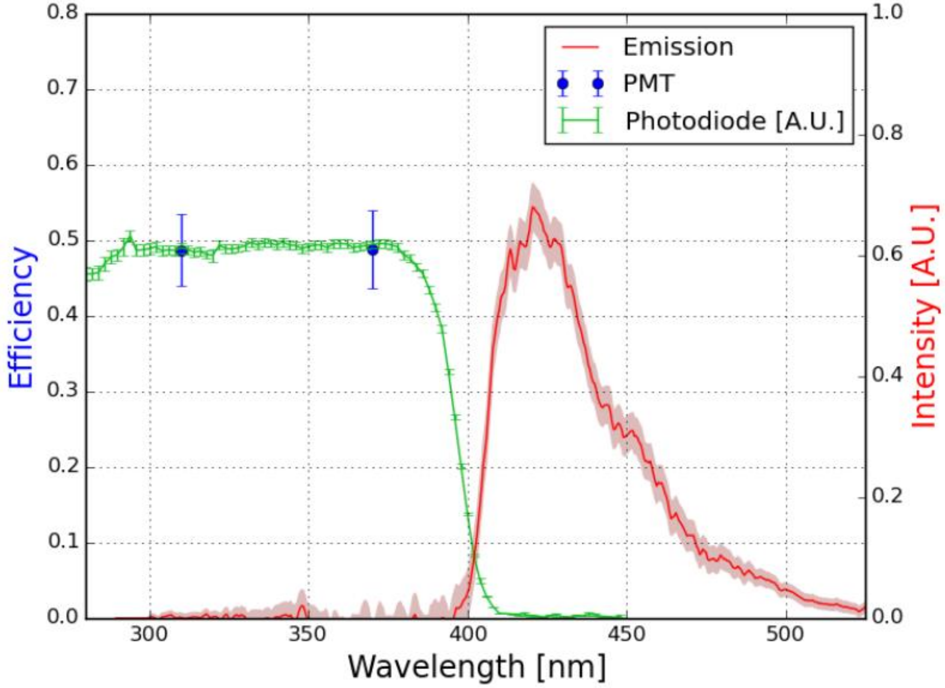
- Dip coater
  - speed control
    - 0-10 cm/min
- dipping speed
  - faster dipping
    - less time for paint to run off
    - thick layer
    - empirical law $h = \frac{av^x}{v+1\frac{cm}{min}}$
- layer thickness determination
  - weigh WLS layer
    - well reproducible





WOM efficiency

Dustin Hebecker
(DESY/HUB)



Measured capture and transport efficiency

$$\varepsilon_{ct} = \frac{\#\ detectable\ photons}{\#\ photons\ injected\ at\ outer\ surface}$$

Optimize paint for:

- Capture and transport efficiency
- Adhesiveness
- Surface quality

Best paint mix:

- 77,31% *Toluene*, 22,29% *Paraloid B72*, 0,13% *Bis-MSB* and 0,27% *P-Terphenyl*
- Projected sensitivity $\gtrsim 2\ \times$ IceCube optical module

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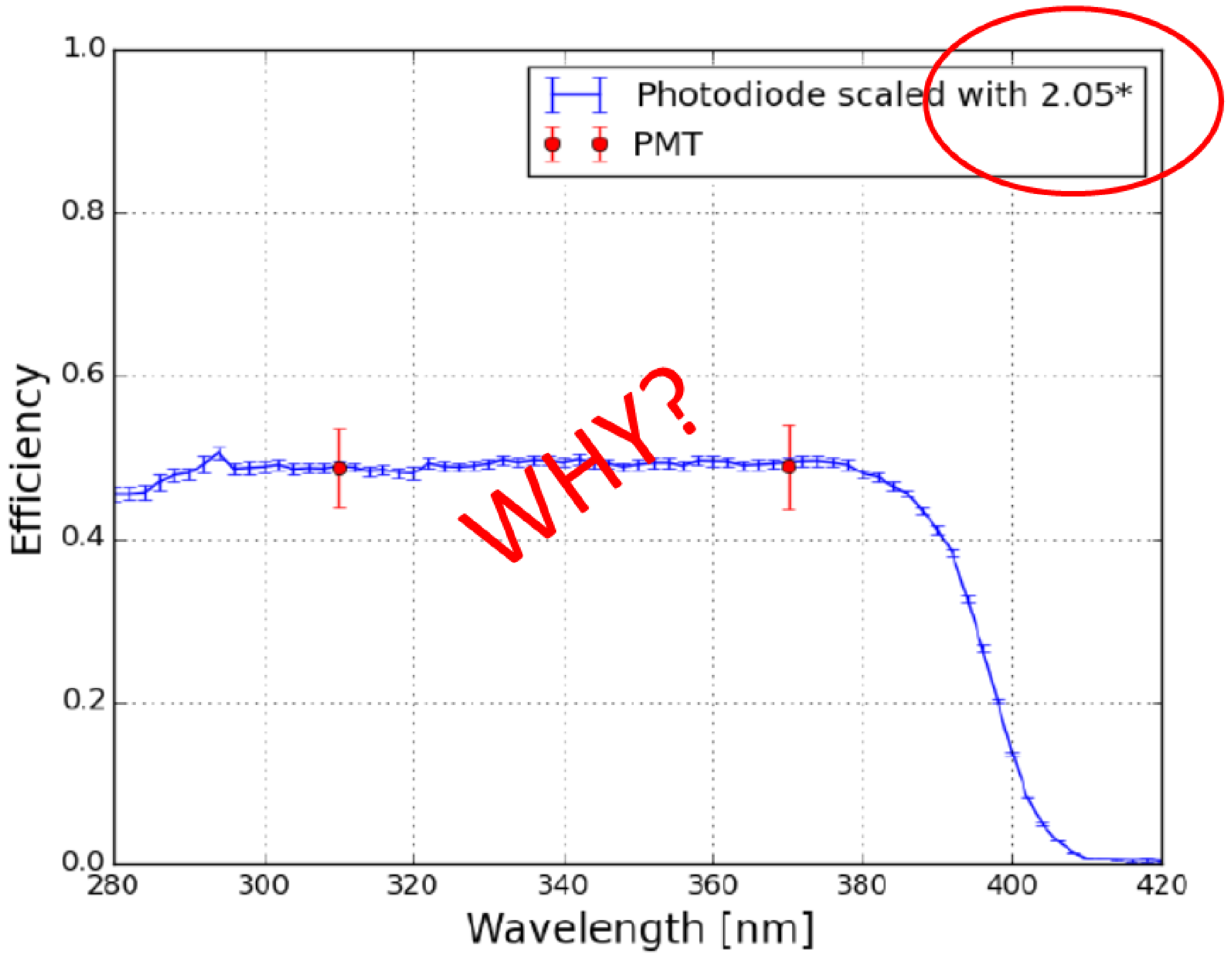
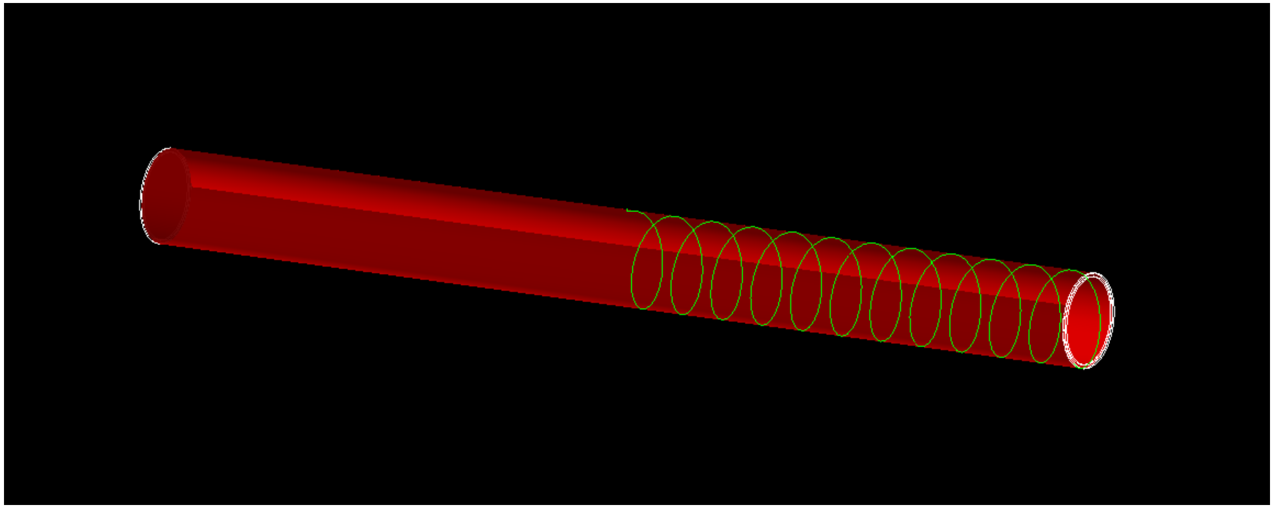
PD and PMT efficiency

Dustin Hebecker
(DESY/HUB)



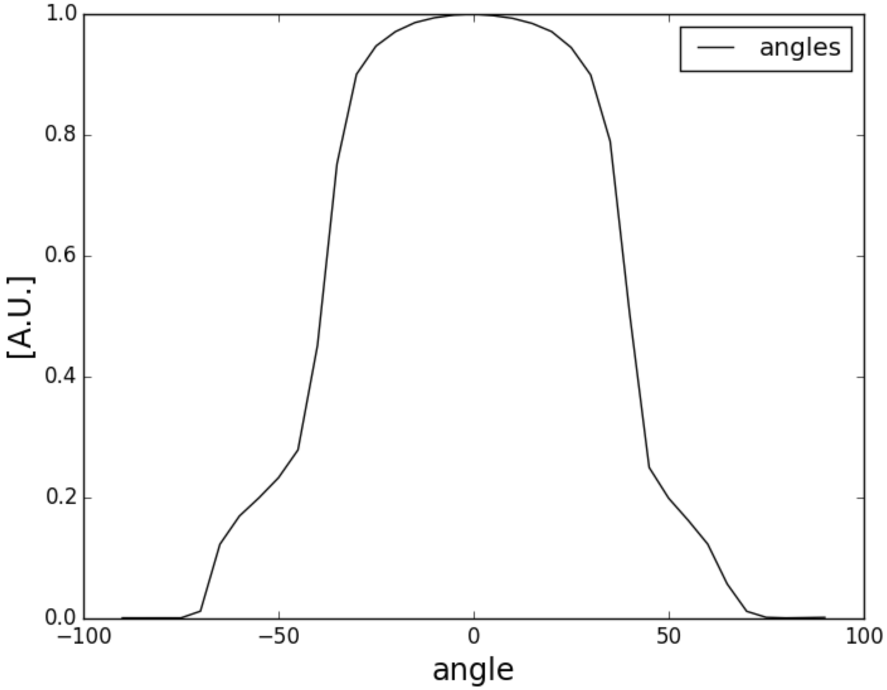
Geant4 simulation of the WOM

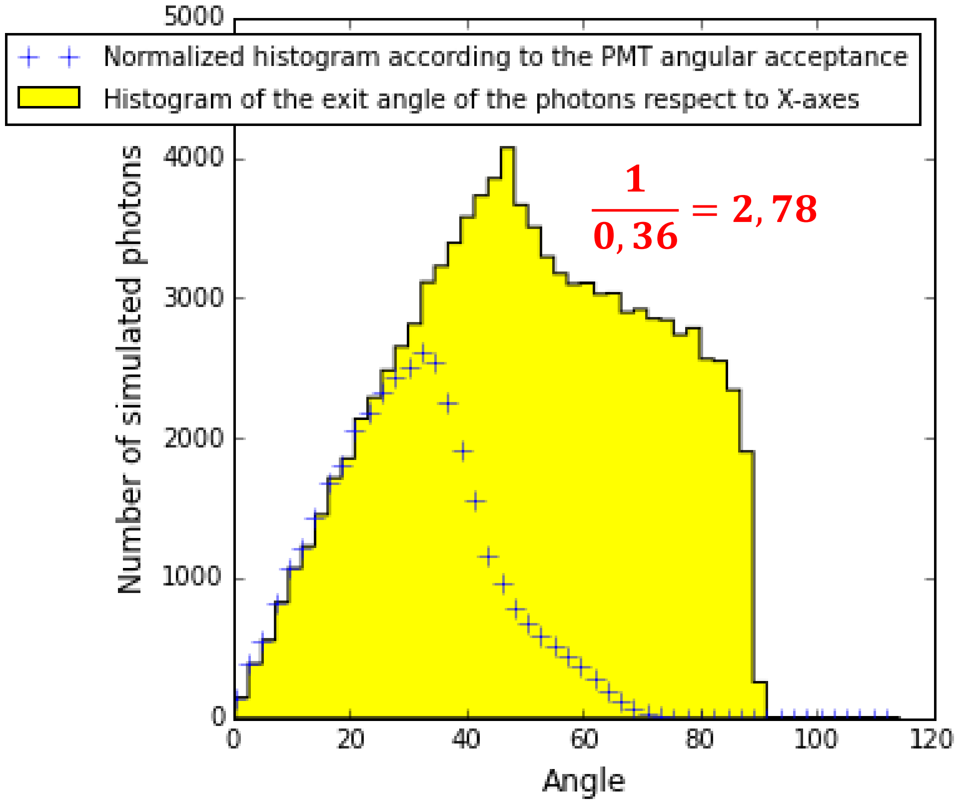
- Simulation of the WOM:
  - PMMA refrective index 1,503
  - length 90 cm
  - inner radius 8,65 cm
  - outer radius 9 cm
- Simulation of the WLS
  - PMP in PMMA
  - refrective index 1,503
  - thickness 0,02 mm



Implemented Rayleigh scattering

Exit angle distribution

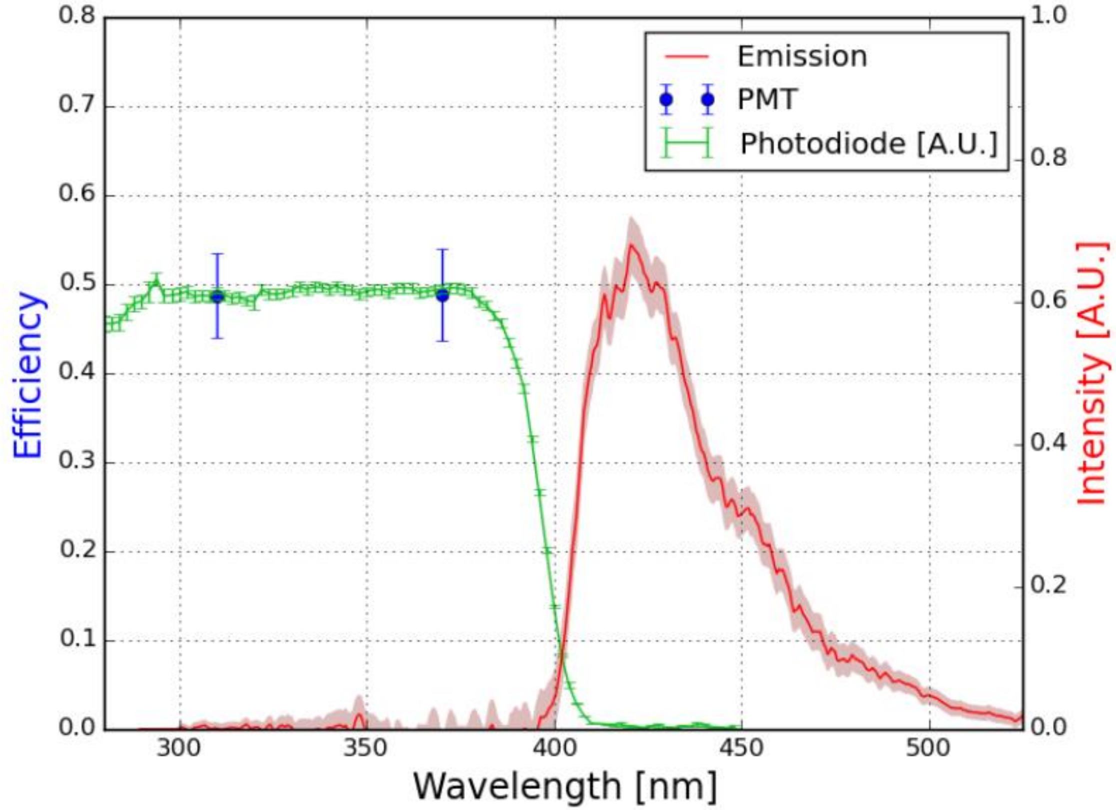


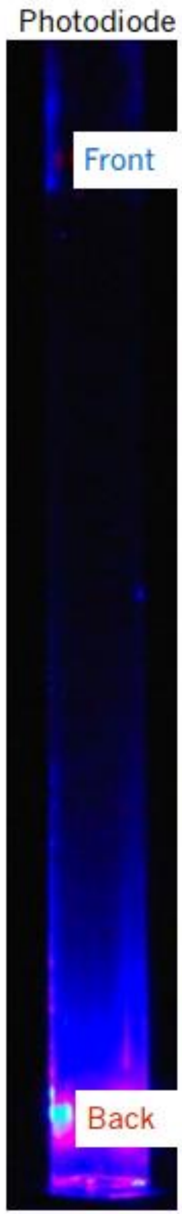


- angular acceptance of the photodiode (Bachelor student Sandra Gerlach at Humboldt)
- exit angle distribution of the photons respect to the tube axis

Attenuation

- Theoretical efficiency
  - $\varepsilon_{WLS} = 80 - 100\ \%$
  - $\varepsilon_{TIR} = 74{,}6\ \%$
  - $\varepsilon_{WLS} \cdot \varepsilon_{TIR} > 60\ \%$
- Sources of losses?
  - Q.E. in plastic
  - absorption
  - Rayleigh or Mie scattering



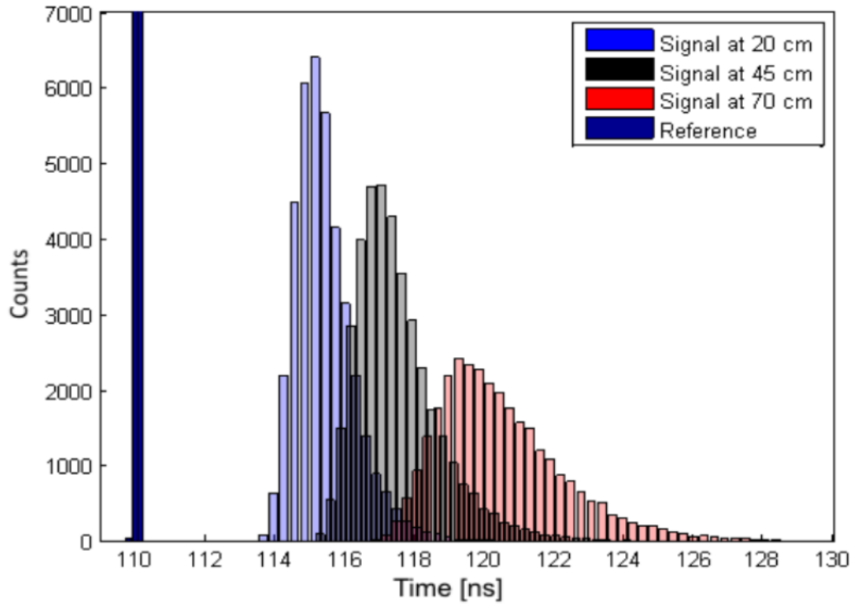


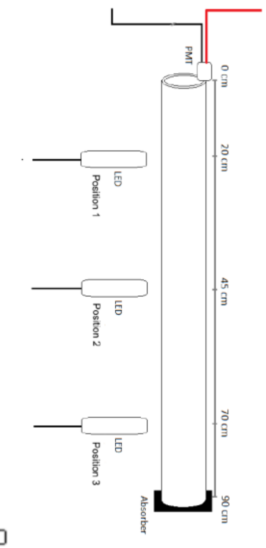
- Photon transit times is affected by light paths
  - Light guide
  - WLS decay time

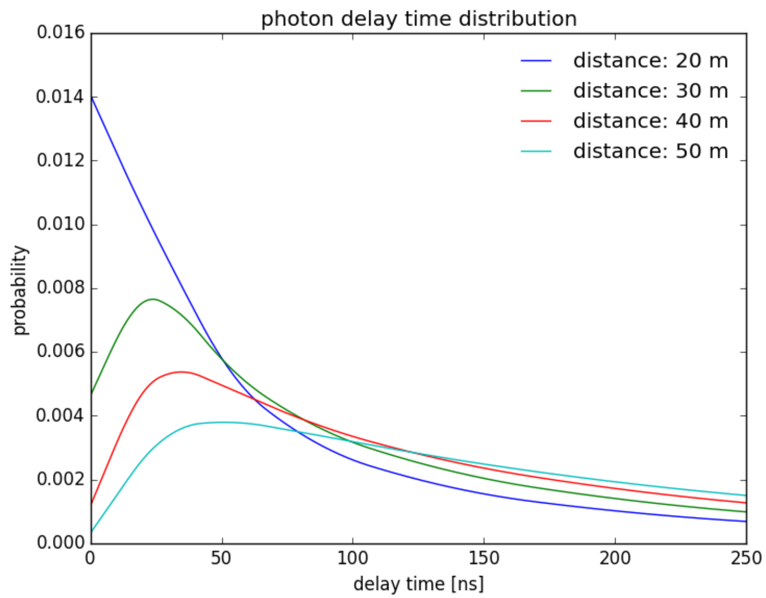
- reference signal is from a sub-nanosecond LED pulser

- overall FWHM of $\approx 10\ ns$

- Information about absorption and scattering

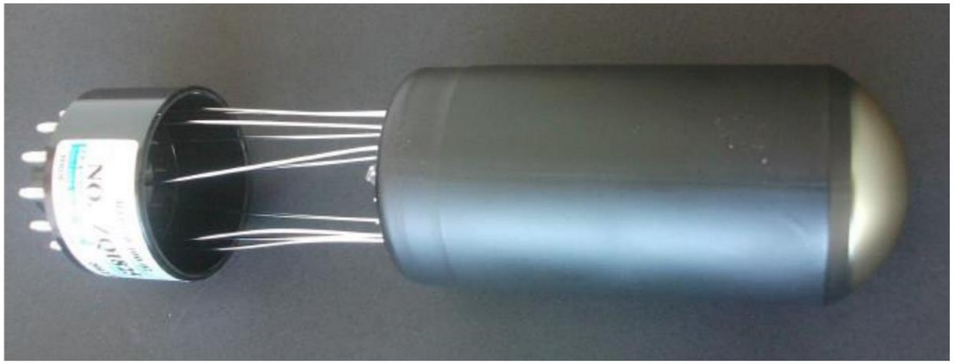


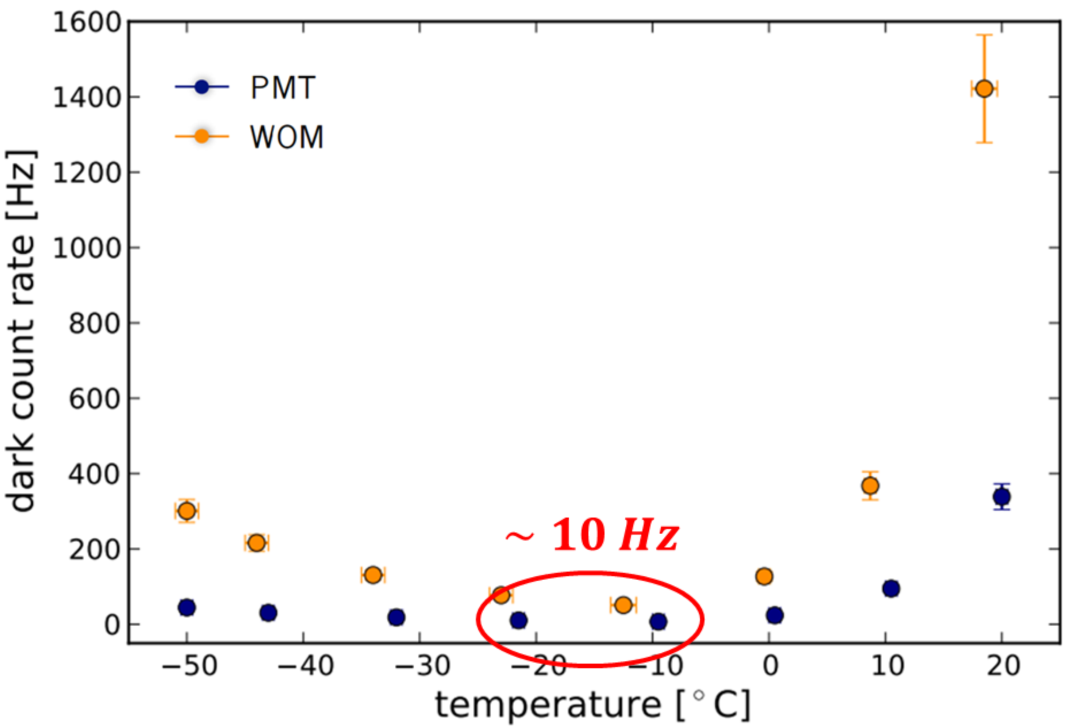




Dark count rate

Krystina Julia Sand
(JGU Mainz)





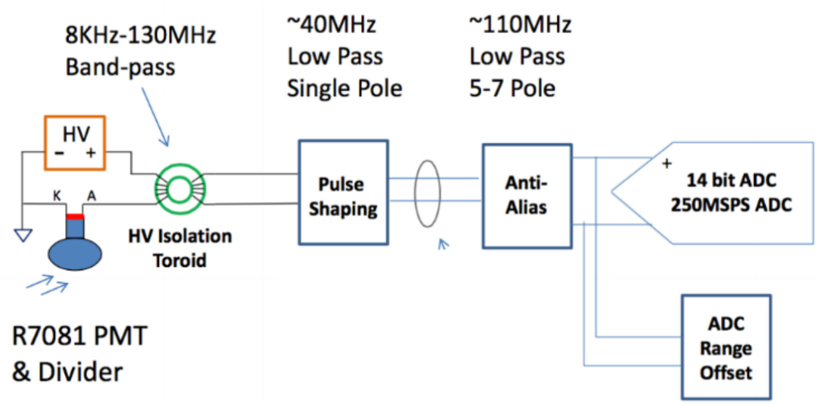
- Hamamatsu R11920-100 PMT
  - Disigned for the CTA experiment
  - 1.5 inch in diameter
  - High Q.E. (32-35% at 350 nm)
  - Low dark noise rate
  - 8 dynodes (low gain)

- Low dark count rates for the PMT
  - $\sim 10\ HZ$

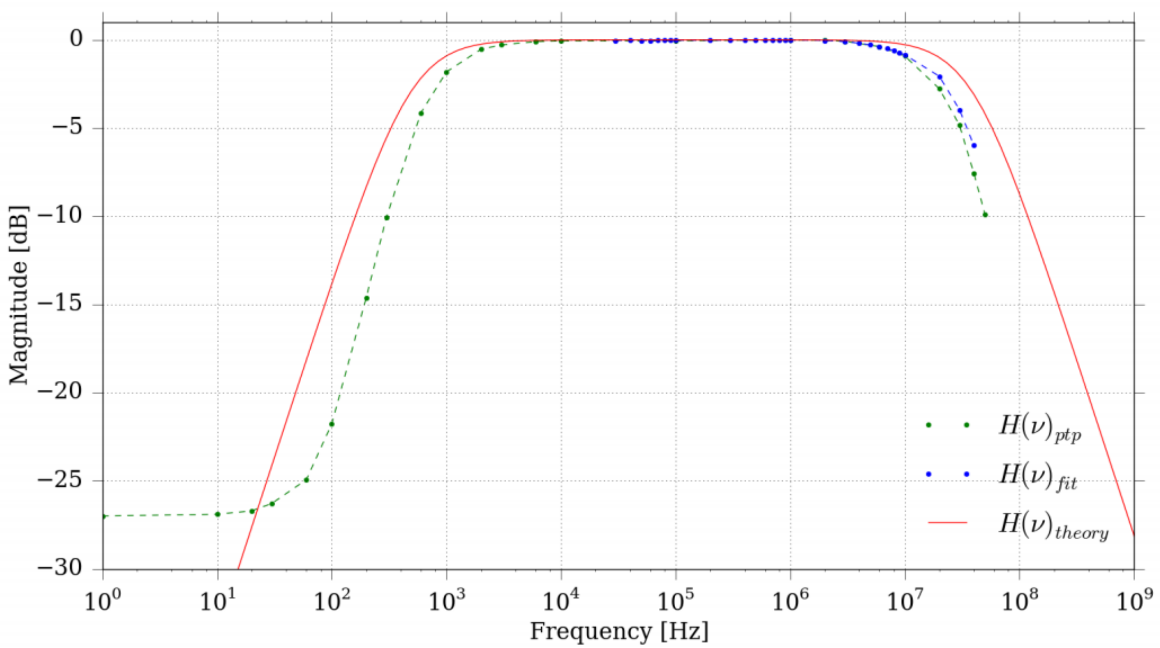
- High dark count rates for PMT and WOM
  - glass end-caps (borosilicate)?

NEW MEASUREMENTS!!!

- IceCube Gen-2 readout
  - Continuous digitizer (DDC2)
    - 250 MS/s @ 14 bit
  - firmware trigger in FPGA

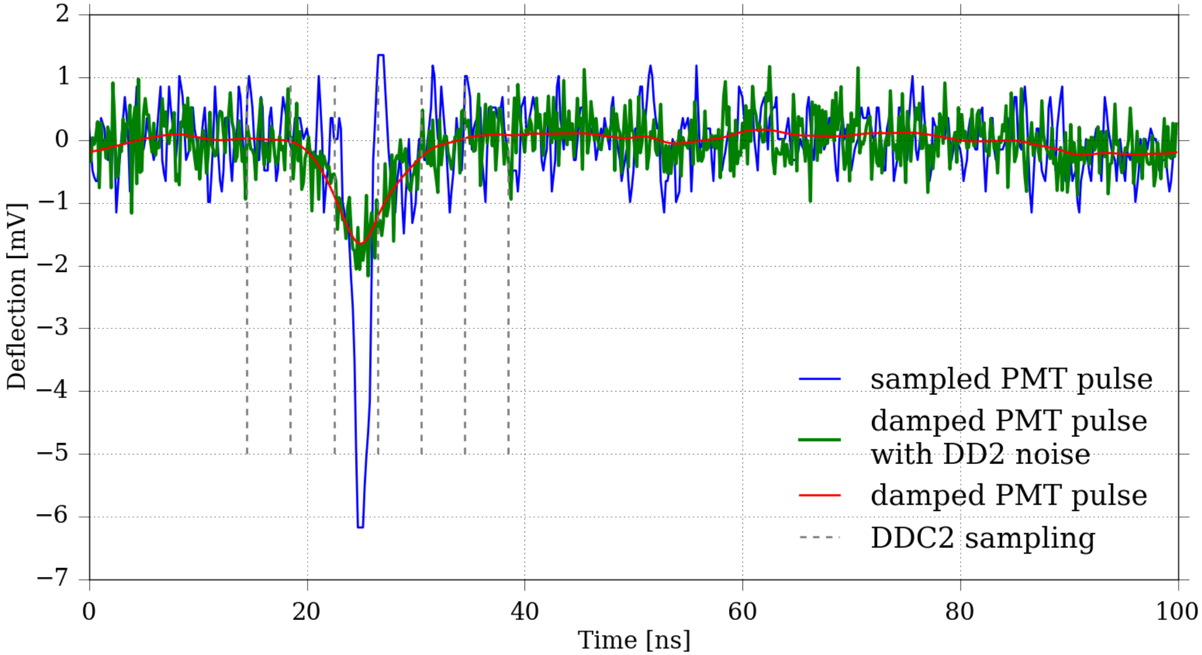


- Performance
  - low noise (1.7 counts RMS)
  - good linearity
  - PMT pulse width $\sim 5\ ns$



Read-out challenge

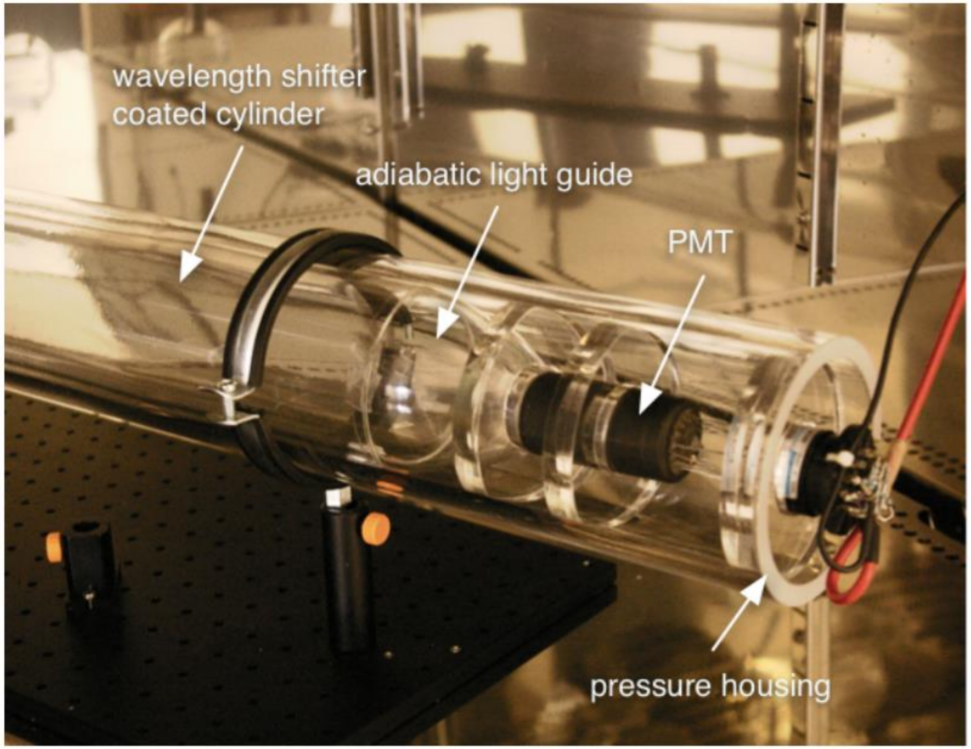
Carl-Christian Fösig
(JGU Mainz)



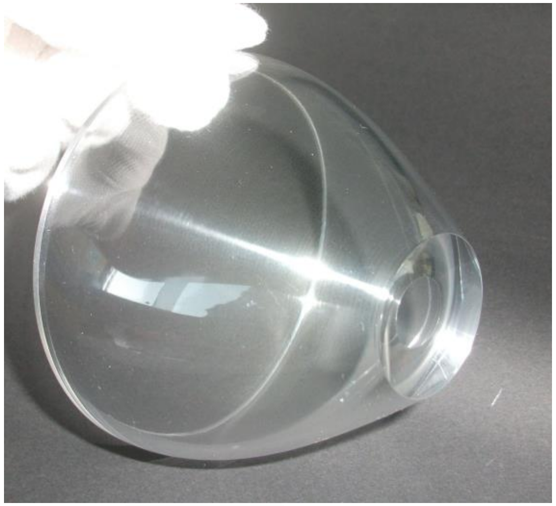
- Result
  - Low PMT gain
  - Short pulses
- Requirements
  - High bandwidth
  - High sensitivity

3 different PMTs will be characterized soon!

WOM status



wavelength shifter coated cylinder
adiabatic light guide
PMT
pressure housing



Summary

- **Wavewlength shifting Optical Module**
  - high effective area at low noise

- **Photon collection efficiency**
  - very good results
  - angular acceptance for the PD measurements (simulation)
  - absorption or scattering sources of losses
  - new measurements with casted PMMA tubes (better optical properties)

- **PMT & Electronics**
  - $10\ Hz$ noise level reachable
  - read-out tests for different PMTs

- **Prototype assembly**
  - will be completed soon!

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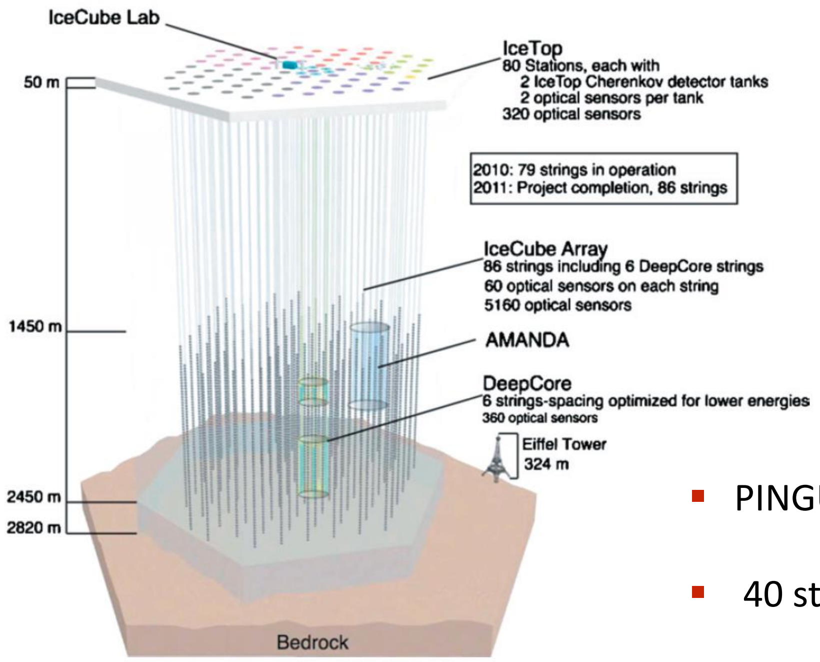
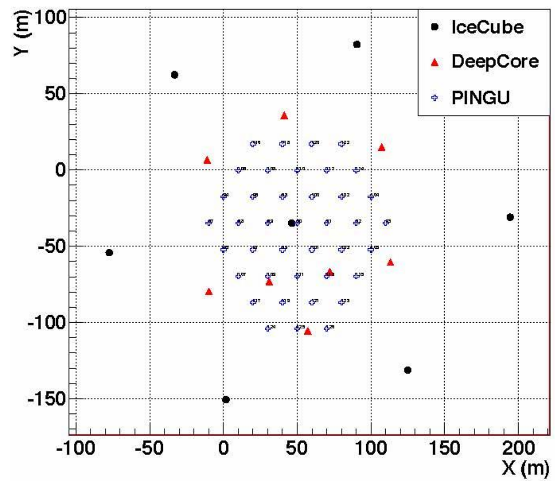
Backup

- Backup slides from here on out

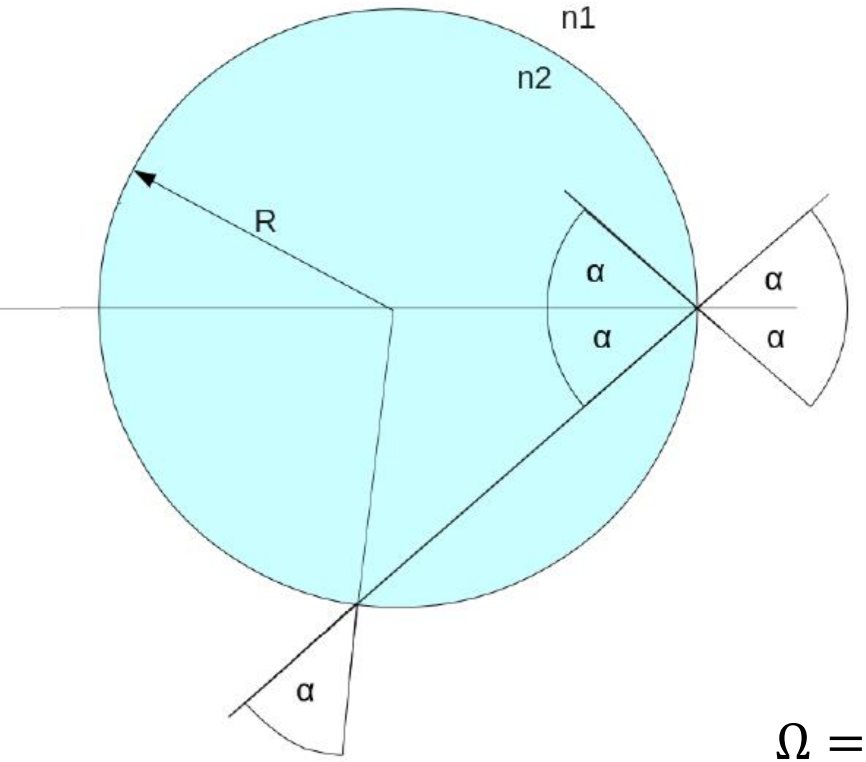
IceCube & PINGU

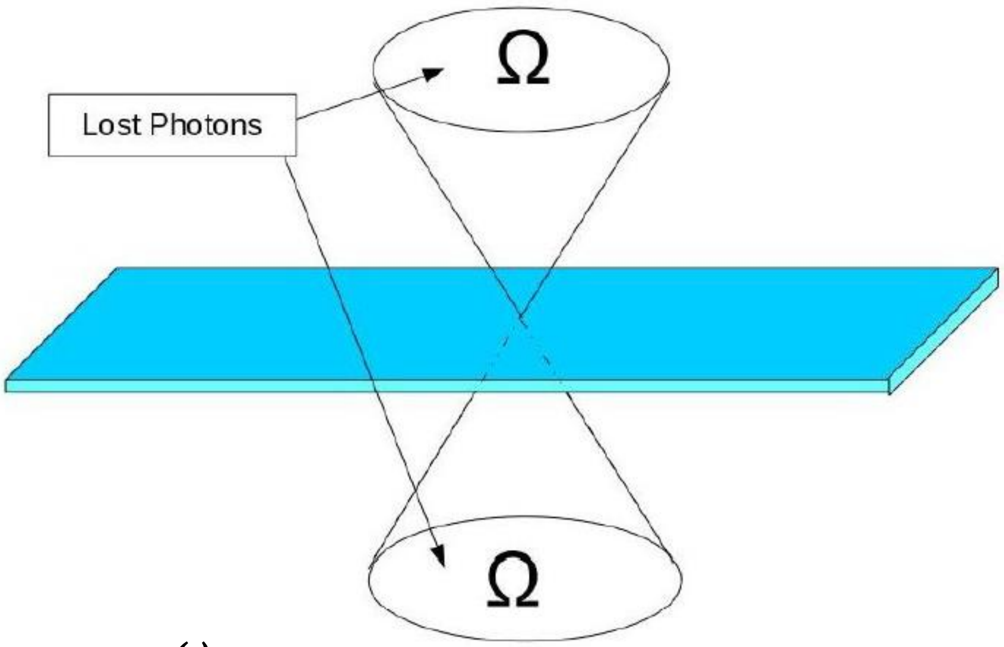




- PINGU – Precision IceCube Next Generation Upgrade
- 40 strings, 22 m apart
- 96 optical modules per strings, 3 m apart
- Dense instrumentation → Measure neutrinos with energies of a few GeV

Total internal reflaction





$$\Omega = 4\pi \sin^2\left(\frac{\omega}{4}\right)$$

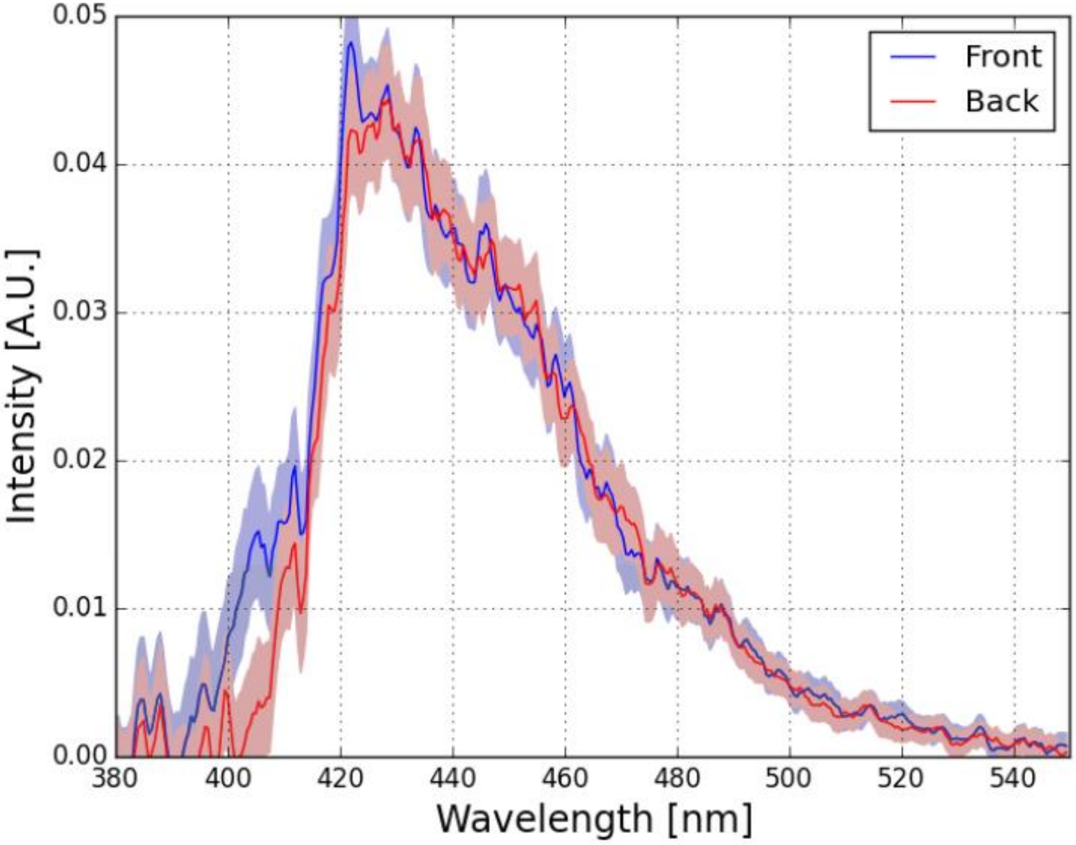
$$\epsilon = 1 - 2\sin^2\left(\frac{\arcsin\left(\frac{1}{1,5}\right)}{2}\right) = 74,6\%$$

(Re-)absorption test

- Shifted light is reabsorbed

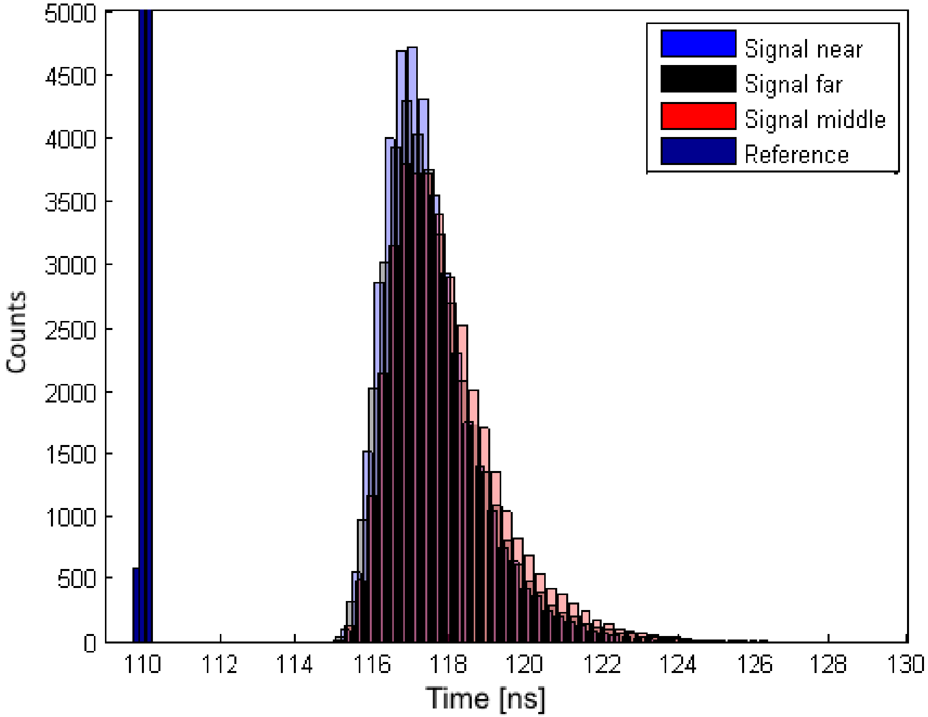
- re-emission
  - likely lost

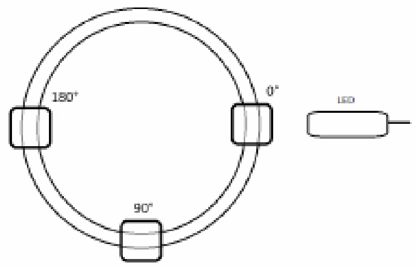
- Emission
  - spectrum indicates small effect



Timing measurements

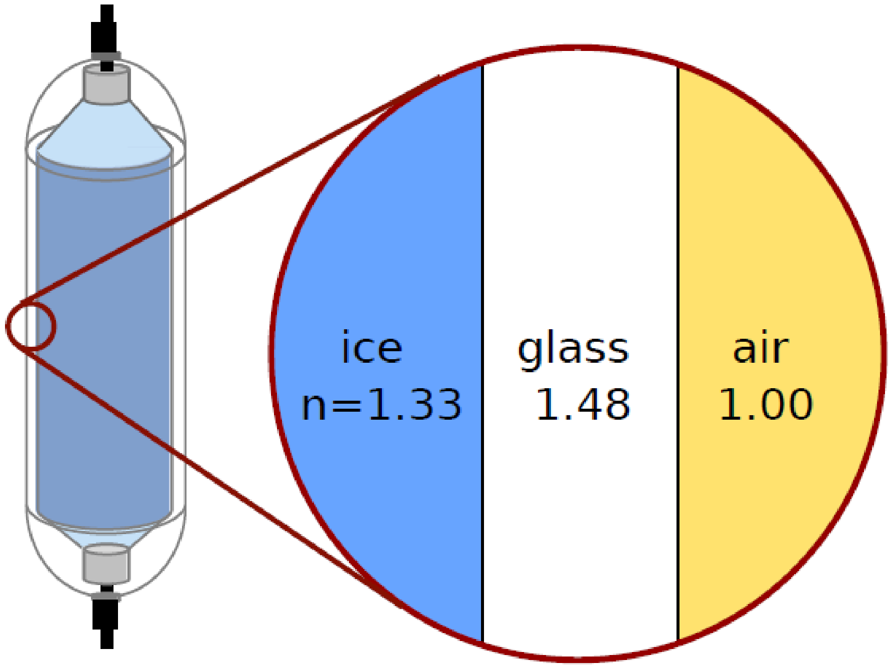
Jannes Brostean-Kaiser
(DESY/HUB)

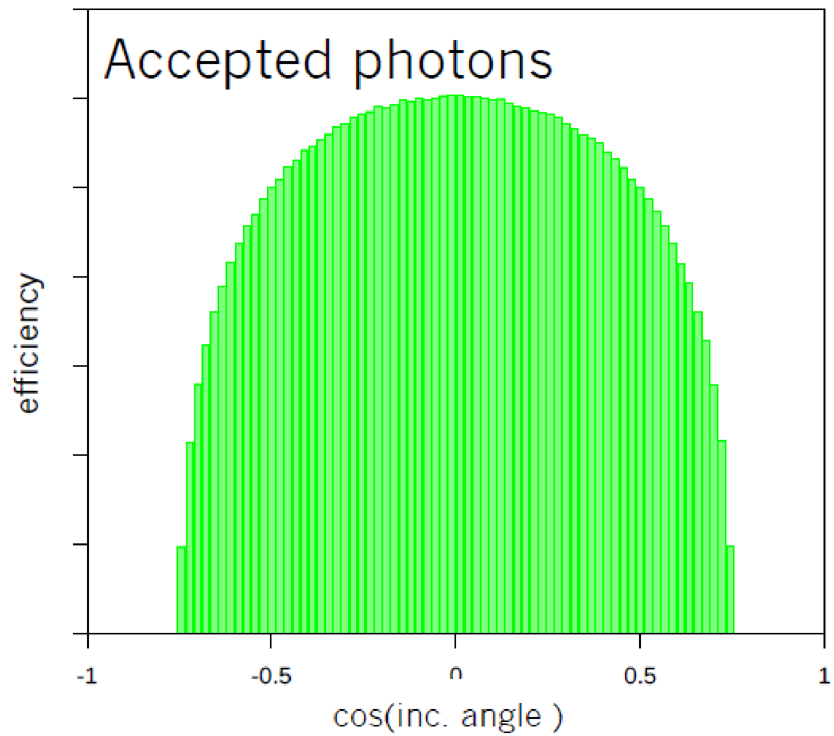




Maximizing Liouville

- Entendue (aperture × solid angle) is constant
- (only) detect photons that enter the WOM





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- Semi-spherical surface grid (lenticular arrays)
  - maximizes acceptance
  - gain **37%** w.r.t. flat