Investigation of photomultiplier photocathodes with an ellipsometer

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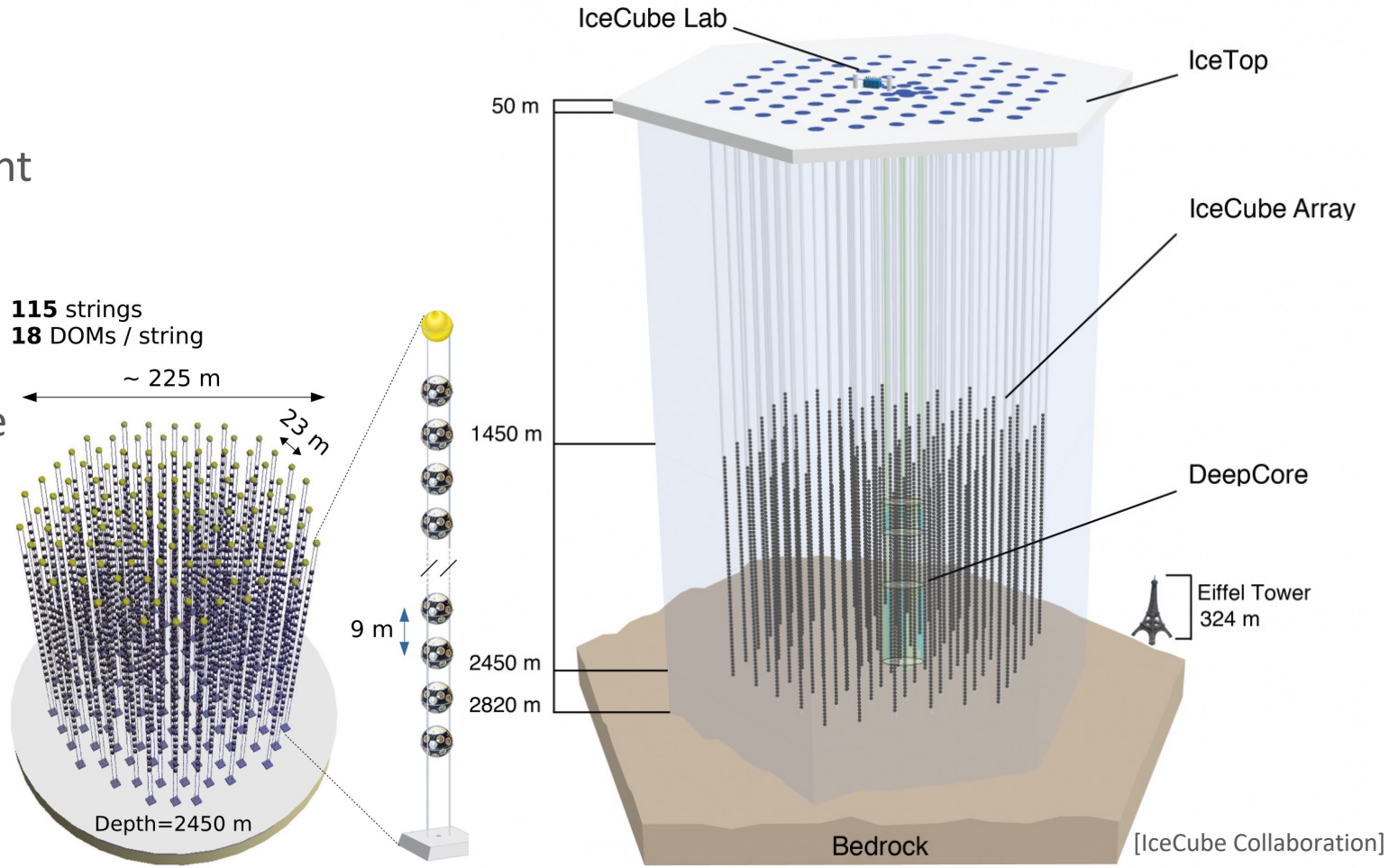
Motivation

- Photomultiplier tubes (PMTs) are a major component of neutrino detectors/ telescopes

  → knowledge of properties is important

- In my current work the focus is on the optical properties of the photocathode and its influence on the PMT performance

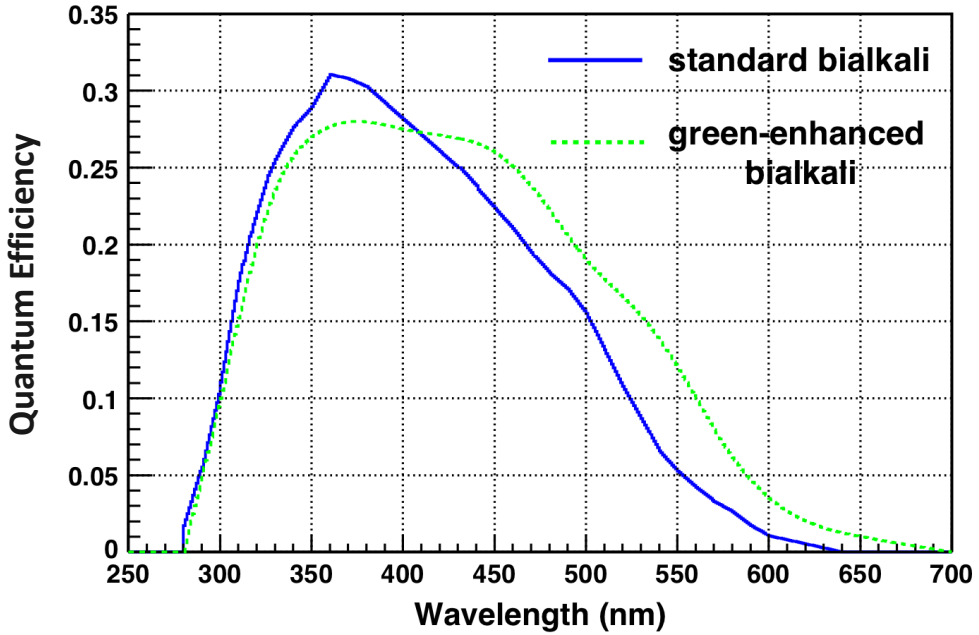


[A. Akindinov, et al., Letter of interest for a neutrino beam from Protvino to KM3NeT/ORCA]

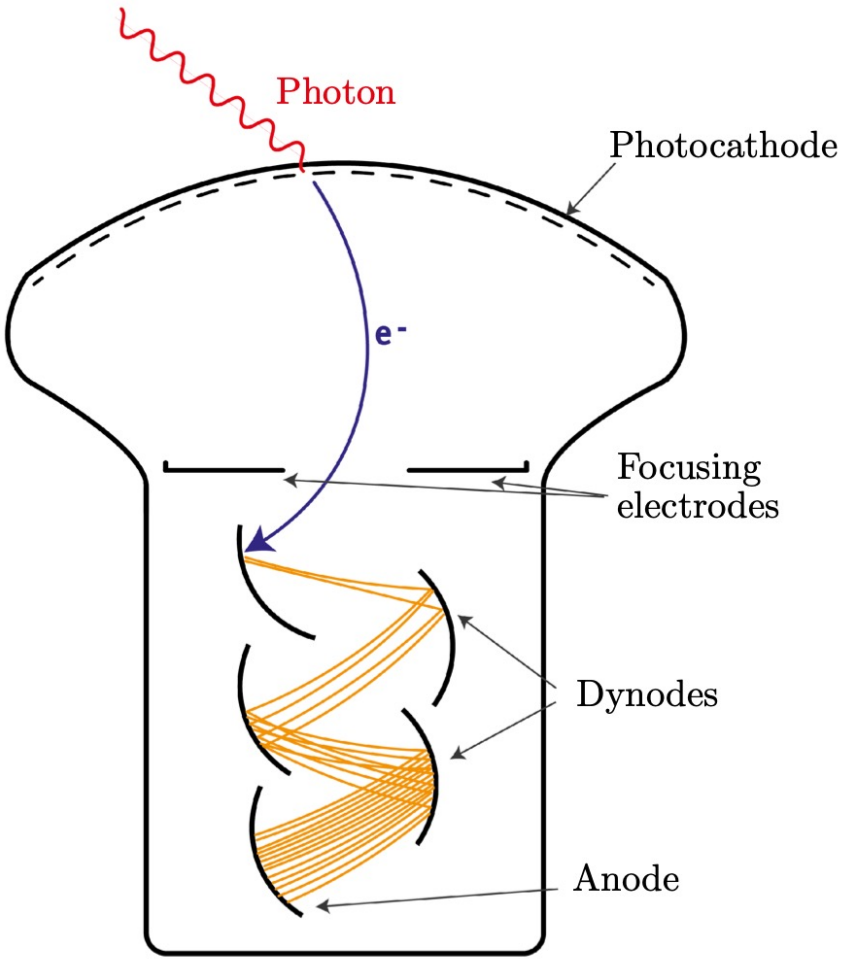
[IceCube Collaboration]

Photomultiplier Tubes (PMTs)

- Detects light by converting photons into an electrical signal via the photoelectric effect
- Photocathode consist of photoemissive semiconductors
  - ➢ Bialkali compositions like KCsSb and RbCsSb



[D. Motta, S. Schönert, Optical properties of bialkali photocathodes]

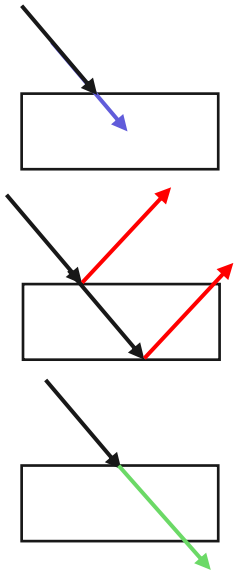


[M. Unland, Master thesis, 2017]

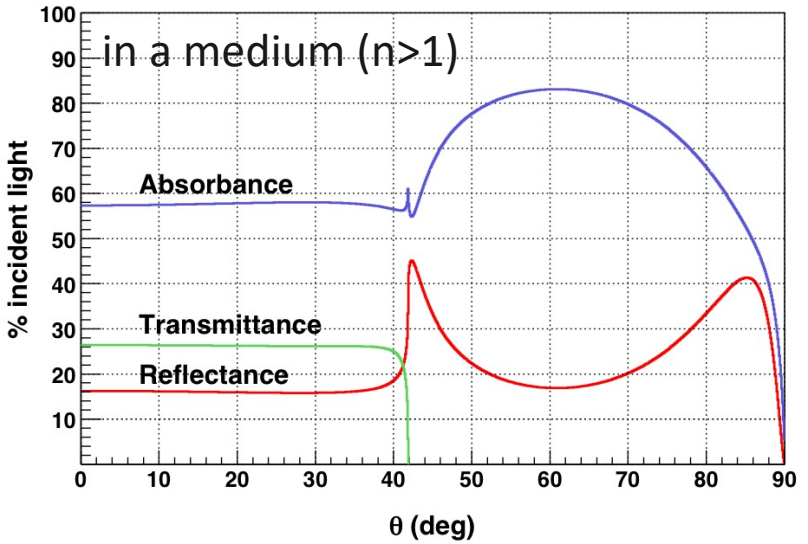
Photon processes

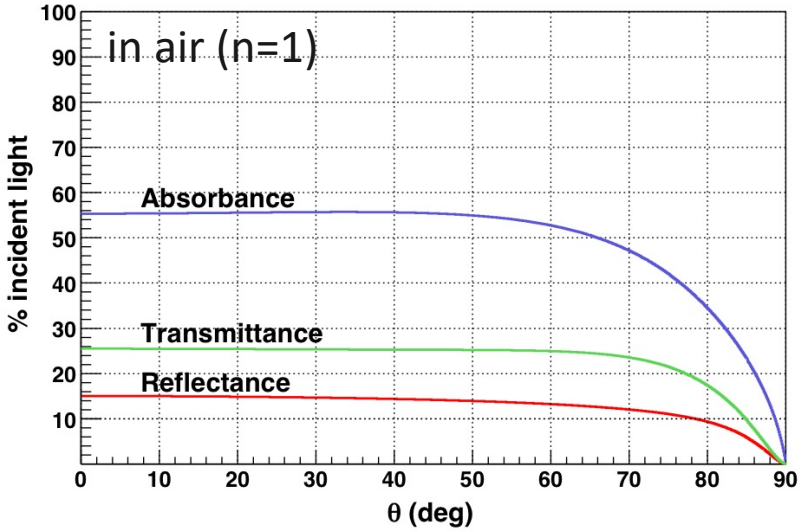
Three possible processes for an incoming photon:

1. Absorption in the photocathode: $\mathbf{A(\lambda, \Theta)}$
2. Reflection at the glass window or at the photocathode: $\mathbf{R(\lambda, \Theta)}$
3. Transmission inside the PMT: $\mathbf{T(\lambda, \Theta) = 1 - A(\lambda, \Theta) - R(\lambda, \Theta)}$



- Depends on the wavelength λ and the angle of incidence Θ of the photon





[D. Motta, S. Schönert, Optical properties of bialkali photocathodes]

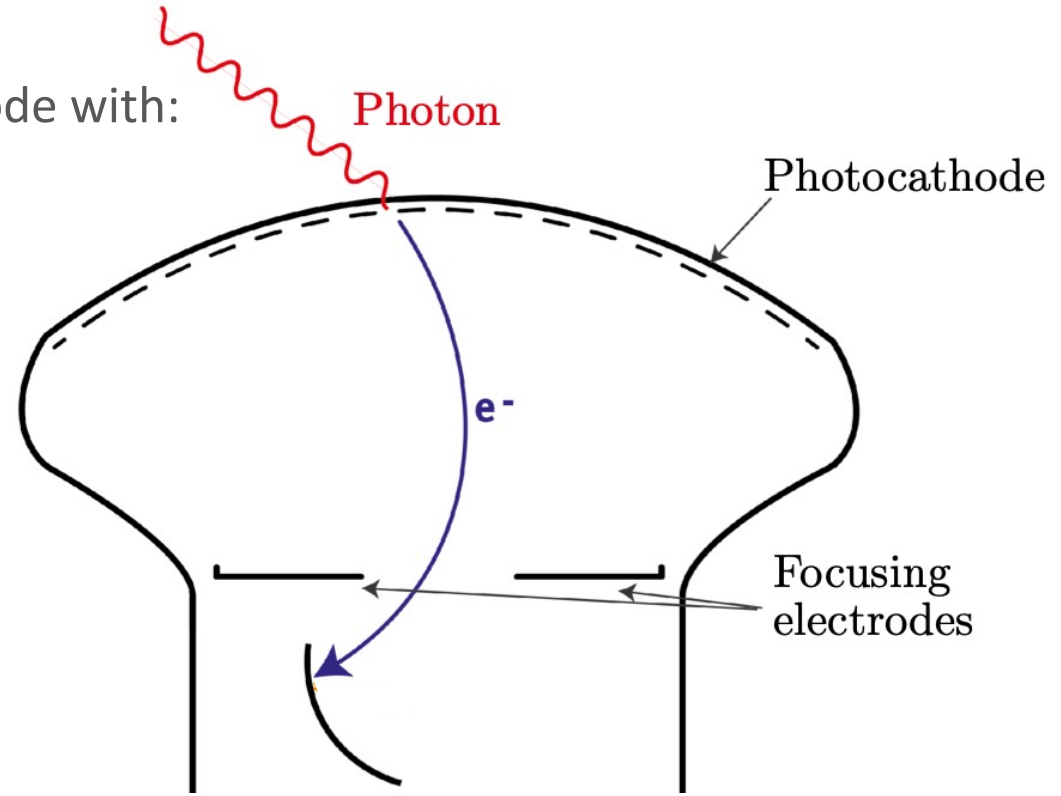
Quantum Efficiency

- Ratio between the number of photoelectrons N_e and the number of incident photons N_p
- Can be related to the absorption probability of the photocathode with:

$$QE = \frac{N_e}{N_p} = A(\lambda, \Theta) \cdot s$$

  - s = escape probability
- Thickness of the photocathode is important
  - Too thick → electron can't escape
  - Too thin → less absorption

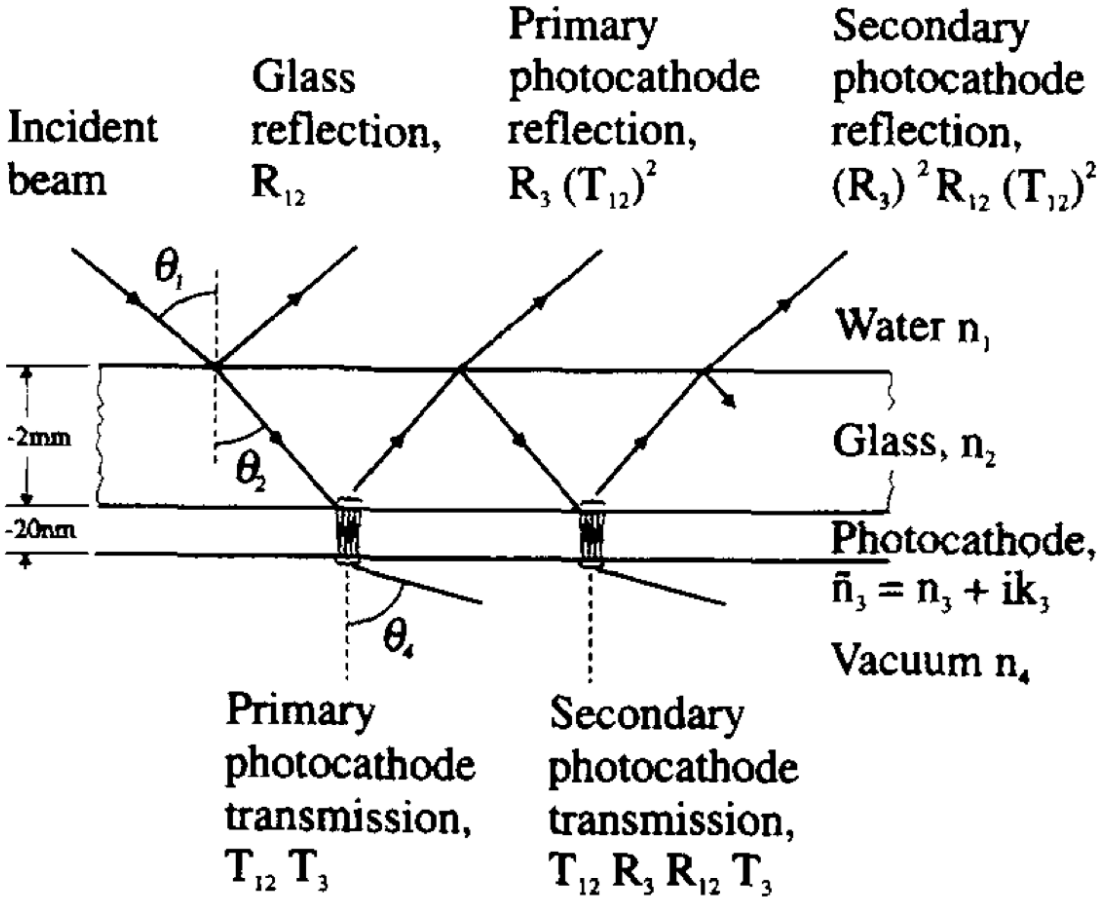
→ How do we get $A(\lambda, \Theta)$?



[M. Unland, Master thesis, 2017]

Optical properties of a PMT

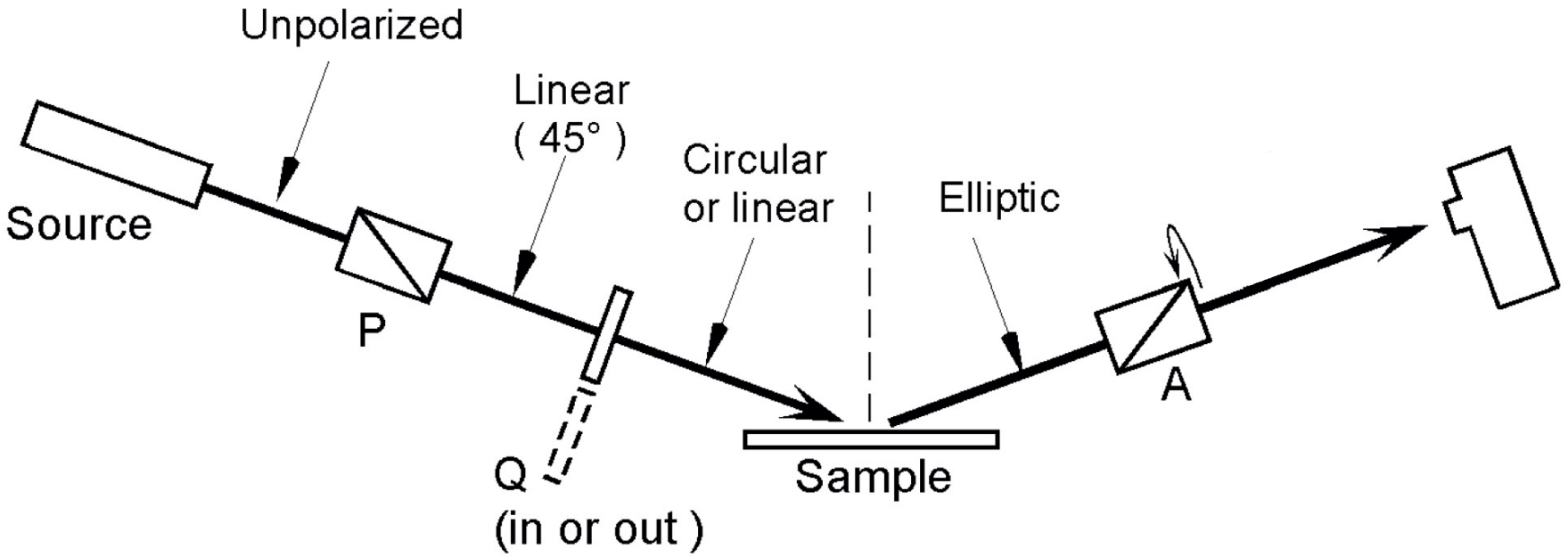
- $A(\lambda, \Theta)$ can be calculated with the Fresnel equations
  - ➢ Optical properties of the PMT are needed
- PMT is equal to a four layer system
- There are two things to keep in mind:
  1. Photocathode is a thin film
     → multiple reflections
  2. Complex refractive index
     → modify Fresnel equation



[M.E. Moorhead, N.W. Tanner, Optical properties of an EMI K_2CsSb bialkali photocathode]

Ellipsometer

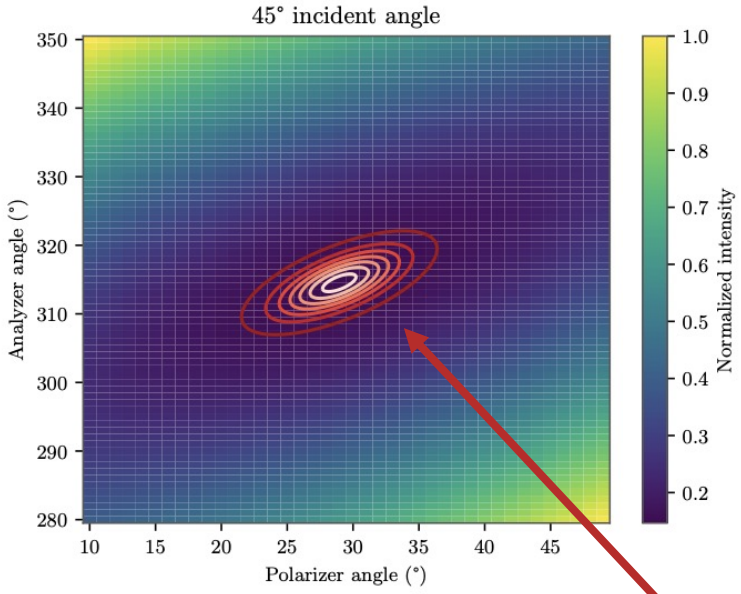
- Measurement of optical properties of a layer by measuring the change of polarization of the light by reflection on a sample



H. G. Tompkins and E. A. Irene, Handbook of Ellipsometry, 2005 (modified)

Ellipsometer

- Change of polarization characterized by the ellipsometer parameters



Intensity measurement

Contour lines of a 2D gaussian fit

$$\tan(\psi) = \frac{|r_p|}{|r_s|},$$

$$\Delta = \delta_{rp} - \delta_{rs}.$$

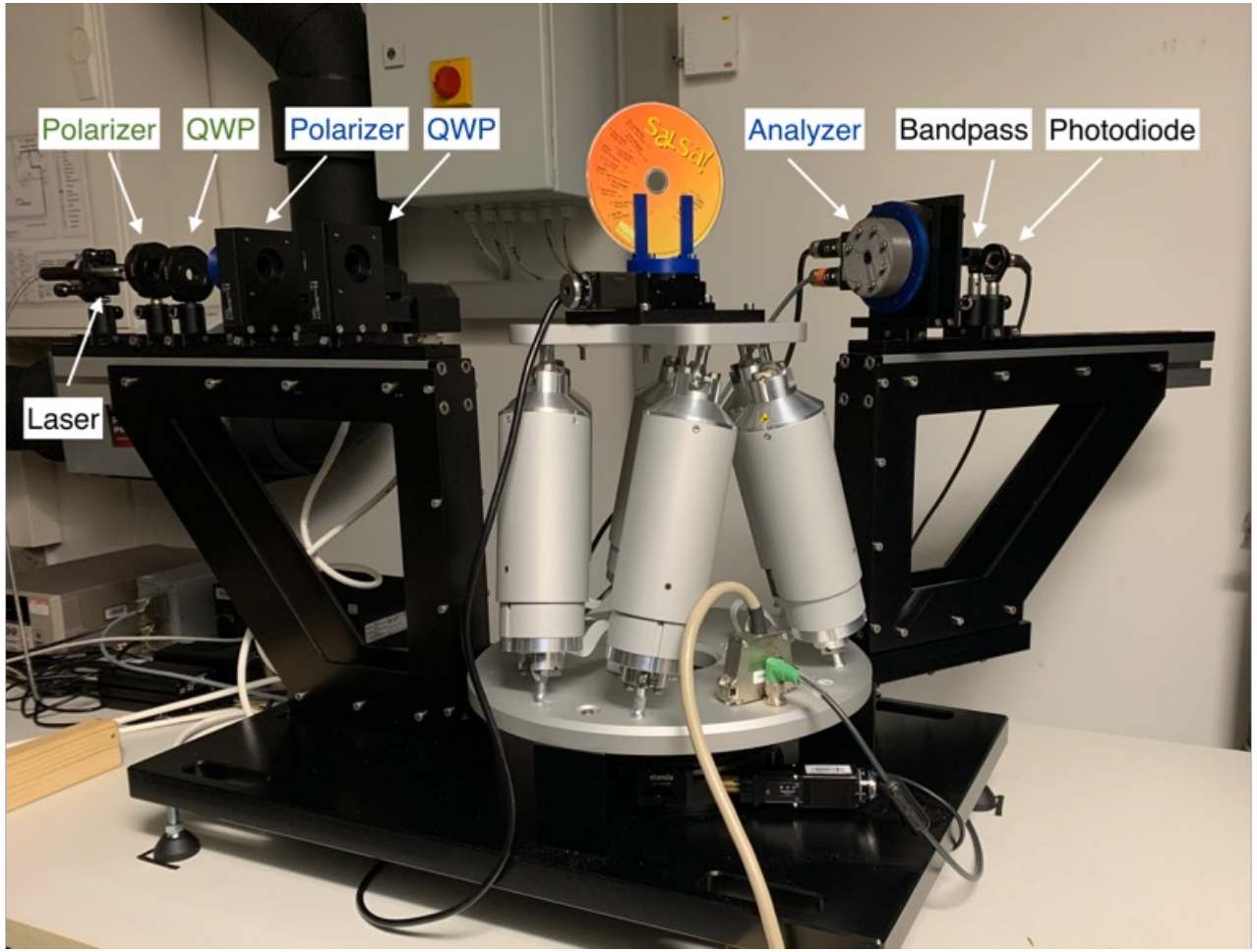
ψ : amplitude ratio
Δ : phase difference

Reflection coefficient

Complex refractive index N= n+ik
Thickness d

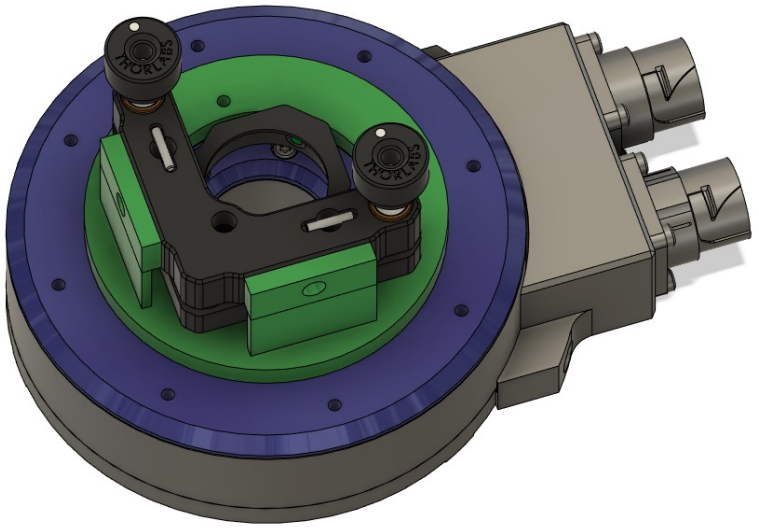
Ellipsometer Setup

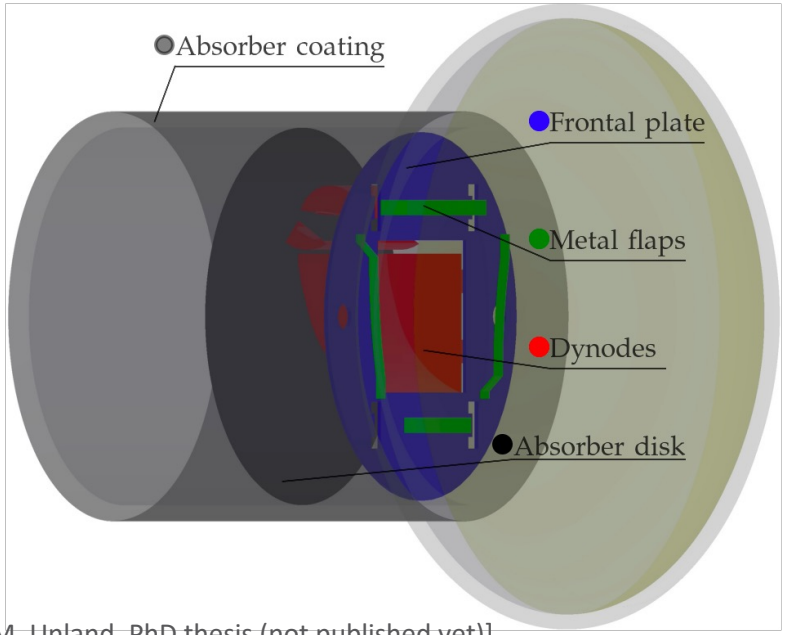
- Optical components and sample mounted on rotation table (motorized, not motorized)
- Possible incident angles: 25° – 65°
- Measurements in the visible wavelength range
- Different types of ellipsometry possible
- Designed for later analysis of the cathode surface of PMTs



Current status

- Re-characterisation of the optical components as they were installed in new mounts (Angular alignment now possible)
- Design of a PMT mount (for 3’’ PMTs)
- Implementation of the properties of a thin layer system in Geant4 for later simulations





[M. Unland, PhD thesis (not published yet)]

Summary and outlook

Summary:

- Set up of an ellipsometer and characterization of its properties
- Upgrade it for measurement of the optical properties of a PMT

Outlook:

- Measurement of a mDOM PMT (IceCube Upgrade module) with different angle of incidence and wavelength at different points of the photocathode
- Compare calculated absorption with the quantum efficiency measurements of the same PMT
- Simulations of the reflection, transmission and absorption of a PMT in Geant4