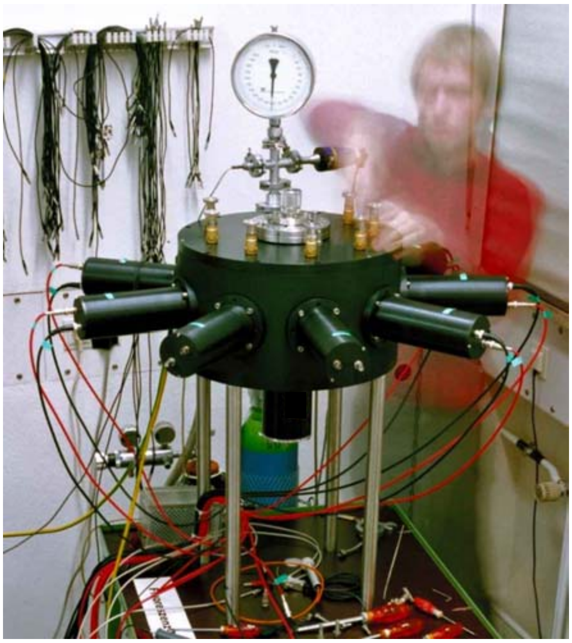
Forschungszentrum Karlsruhe
in der Helmholtz-Gemeinschaft

Universität Karlsruhe (TH)

Optical Elements of the AirLight-Experiment



Interference Filters and Photomultipliers

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Overview

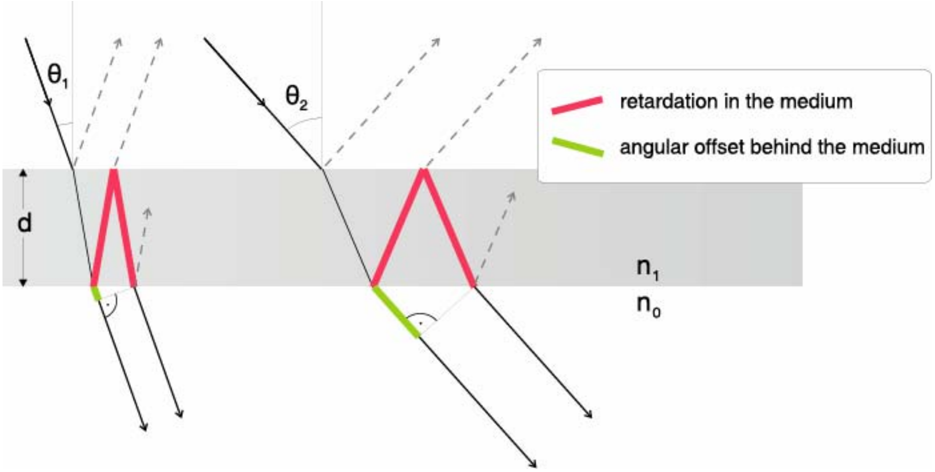
- Interference Filters
  - Theory
  - Measurements
  - Analytical description
  - Effective transmission curves

- Photomultipliers
  - Temperature dependence
  - Spectral efficiency

- Summary & Conclusions

Interference Filters Theory

Thin film interference:



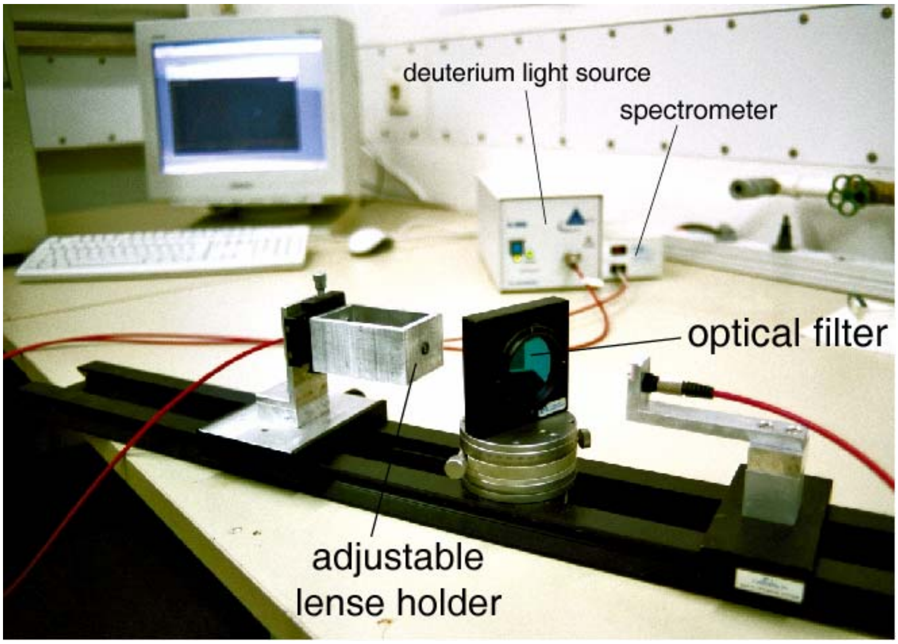
Shift of Central Wavelength (CWL):

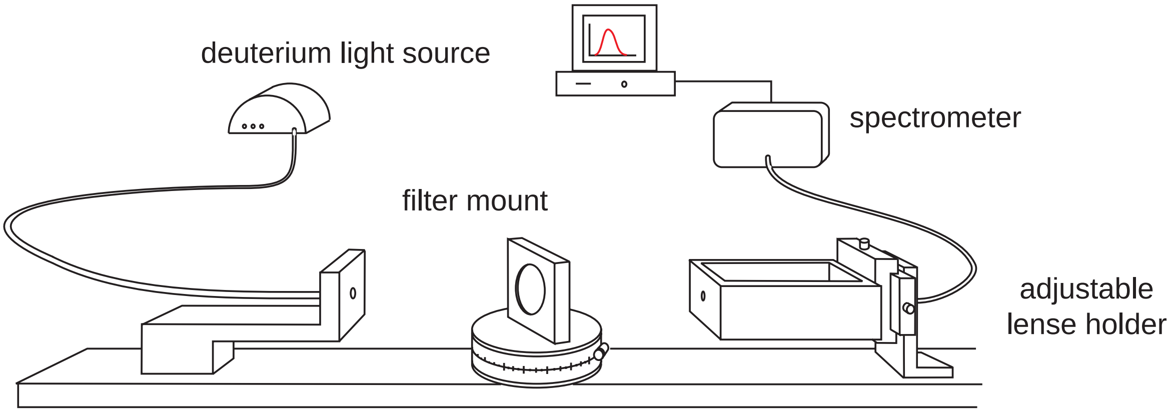
$$\boxed{\lambda_{\mathrm{CWL}} = \lambda_{\mathrm{CWL,0}} \sqrt{1 - \frac{\sin^2\theta}{n^2}}}$$

→ **CWL of filters should be 1-2 nm above the observed wavelength.**

**We use: 318.4 nm, 340.9 nm, 363.4 nm,
381.8 nm, 395.7 nm, 429.9 nm.**

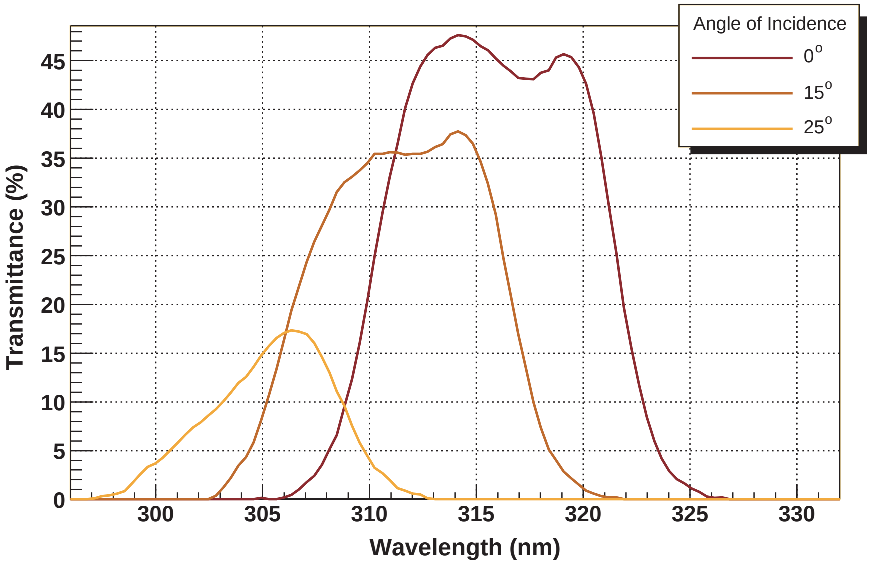
Experimental Setup



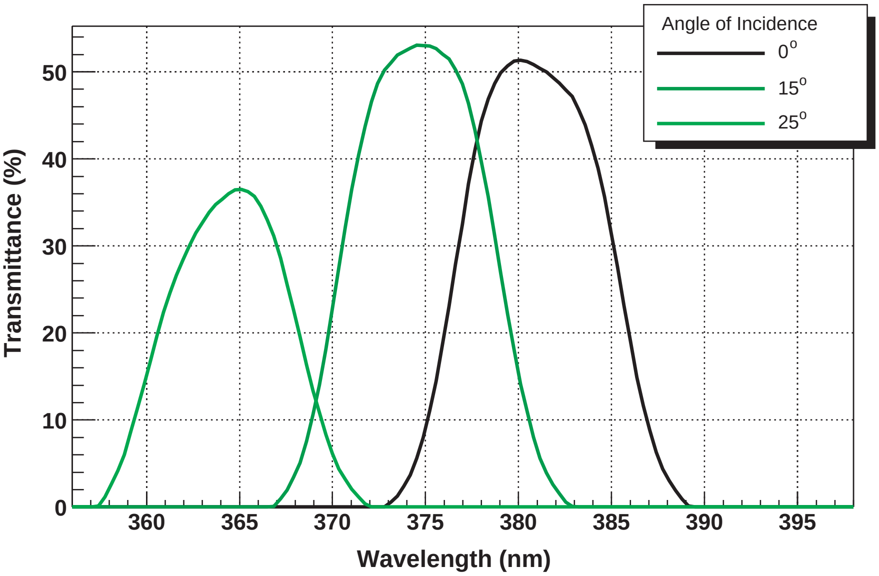


Transmission Curves

For different angles of incidence, Transmission curves change both position and shape:



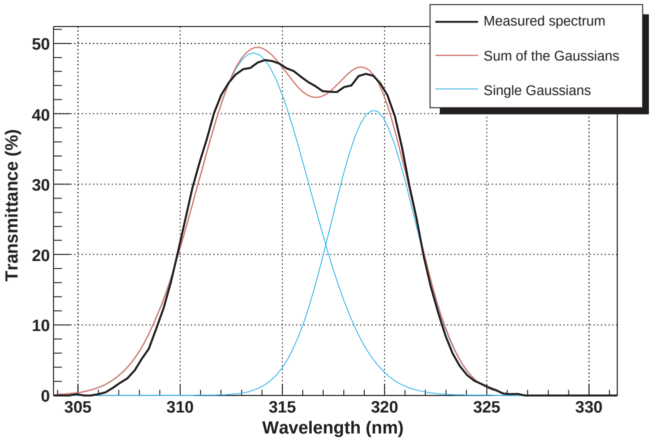
$$\lambda_{\mathrm{CWL},\,0} = 317.1\,\mathrm{nm}$$



$$\lambda_{\mathrm{CWL},\,0} = 381.8\,\mathrm{nm}$$

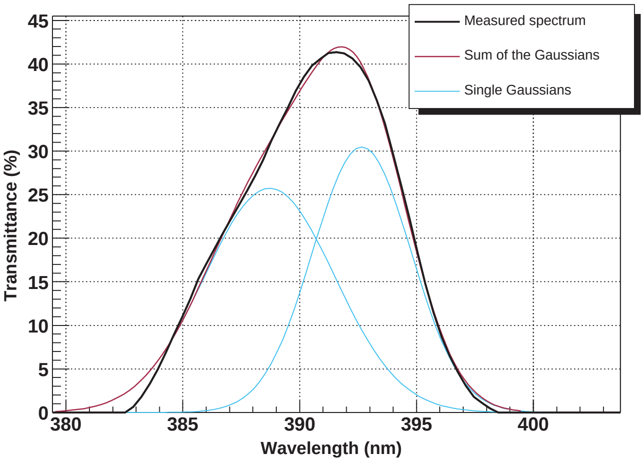
Two-Gaussian-Fit

By two added Gaussians, every individual transmission curve can be fitted well:



$$\lambda_{\mathrm{CWL},\,0} = 317.1\,\mathrm{nm}$$

$$\theta = 0°$$



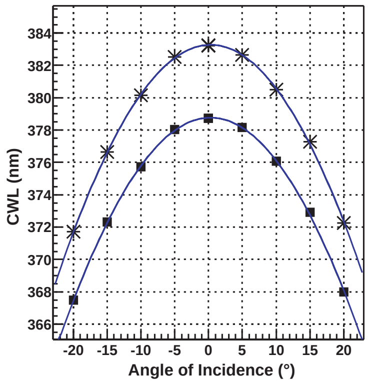
$$\lambda_{\mathrm{CWL},\,0} = 381.8\,\mathrm{nm}$$

$$\theta = 15°$$

Absolute deviations are below 3% Transmittance.

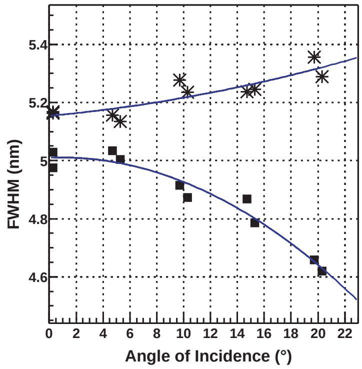
Angle of Incidence Fit

2 Gaussians x 3 Parameters
= 6 θ-dependent Variables



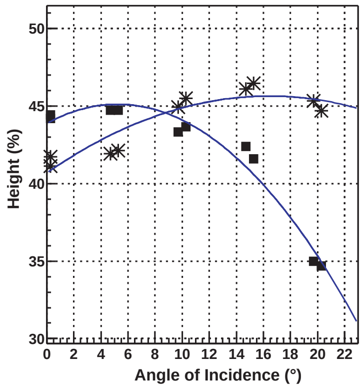
2 x Central Wavelength

→ $$\lambda_{CWL} = \lambda_{CWL,0}\sqrt{1-\frac{\sin^2\theta}{n^2}}$$



2 x Full Width at Half Maximum

→ Parabolic Fit

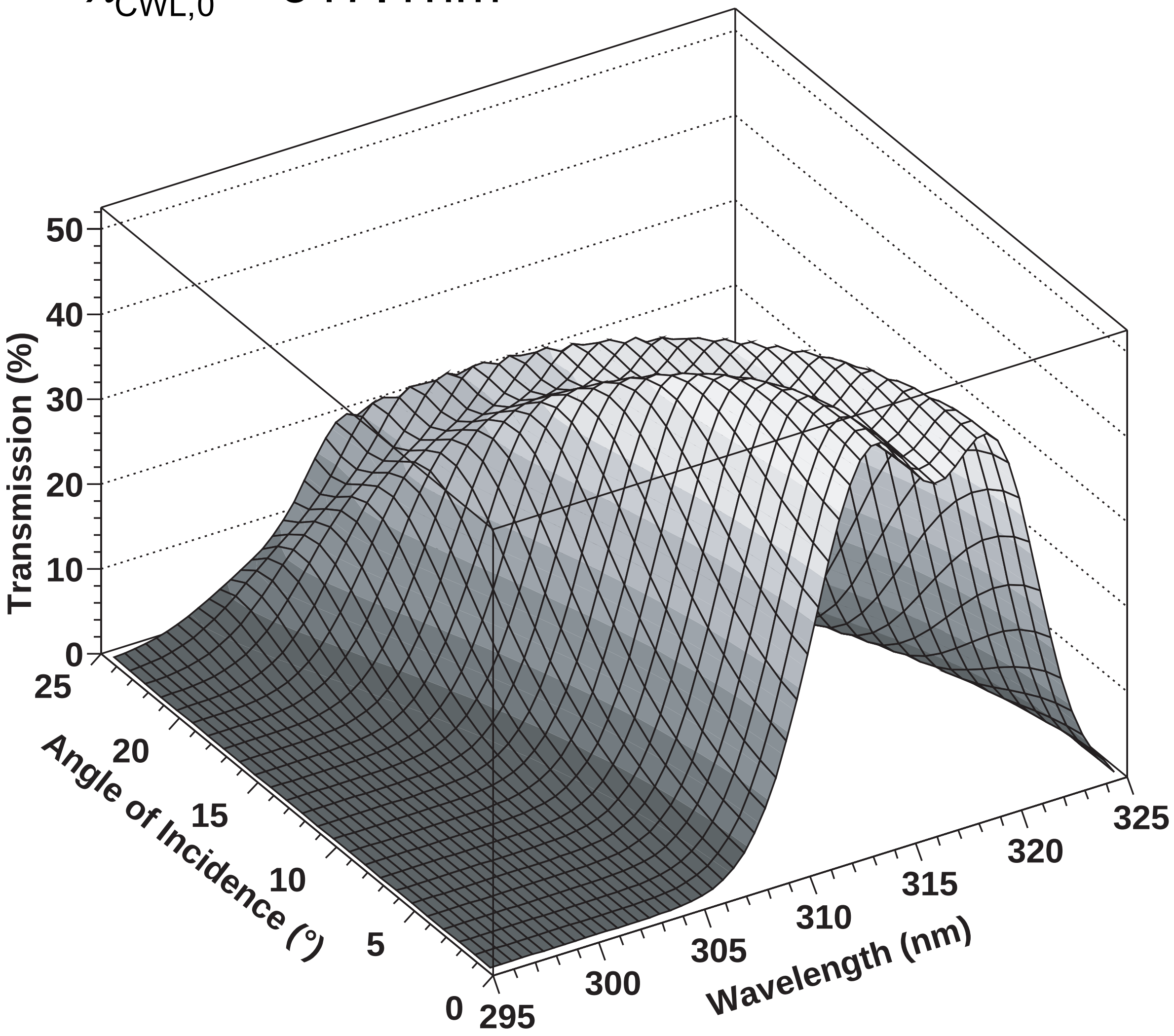


2 x Height

→ Parabolic Fit

Result for one Filter

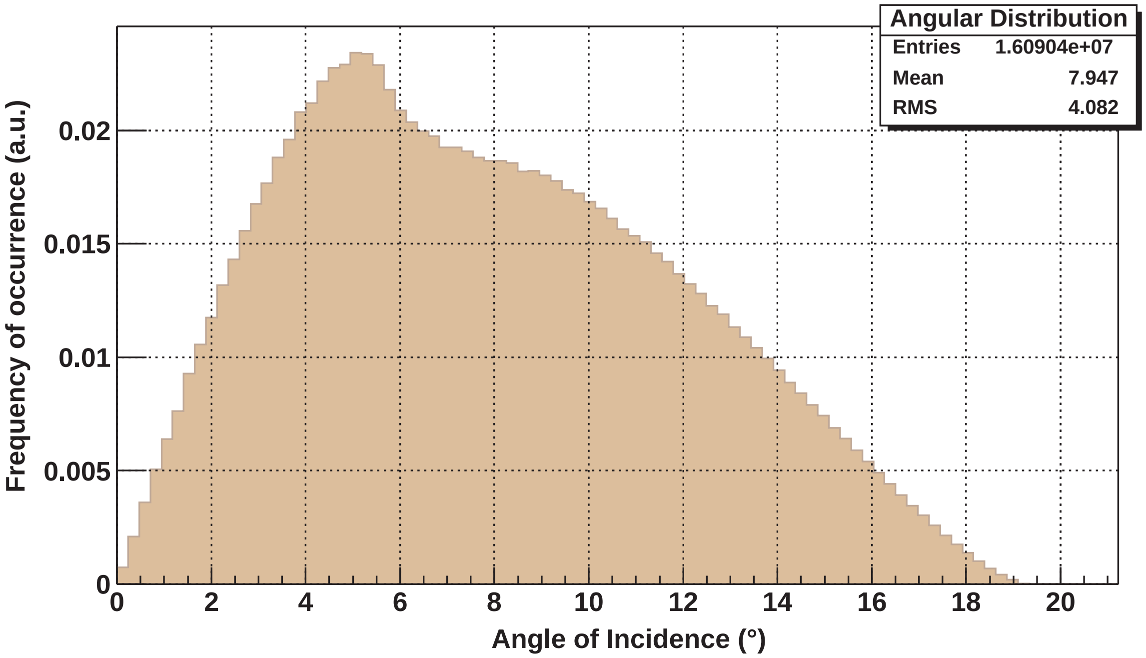
$\lambda_{CWL,0} = 317.1\,\mathrm{nm}$



Angular Distribution of Photons

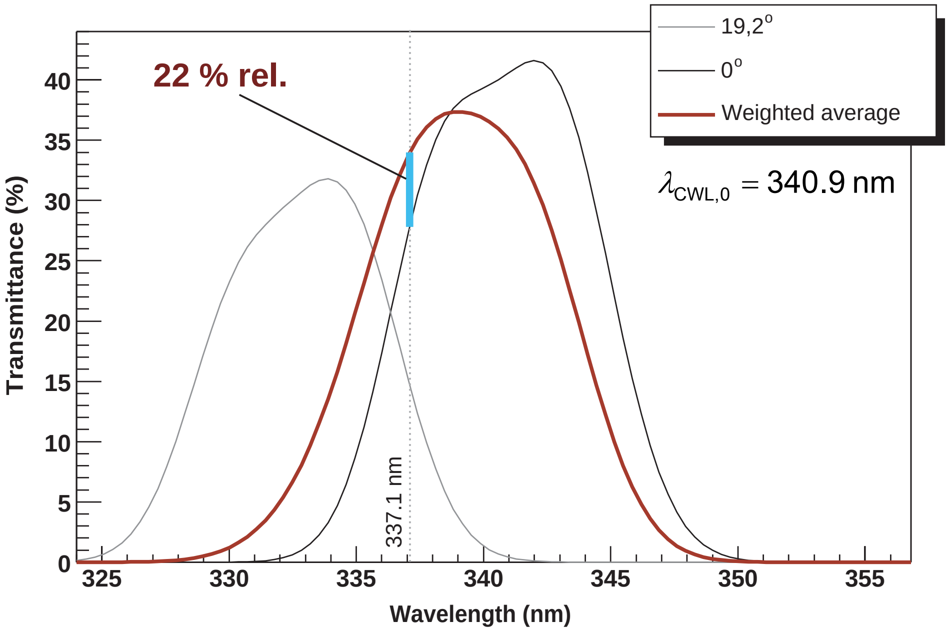
Geometry of the AirLight chamber:

- Electron beam length: 10 cm
- PMT distance: 20 cm
- PMT aperture diameter: 4 cm



Effective Transmission Curves

→ ”Effective Transmisson Curve“ for every Filter can be averaged.



Rel. Error using 0°-Transmission

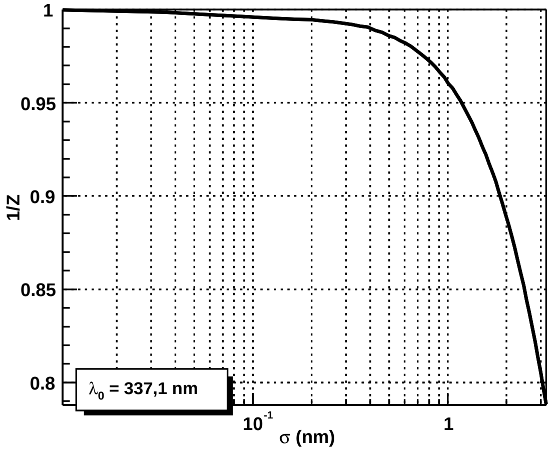
> 20 %

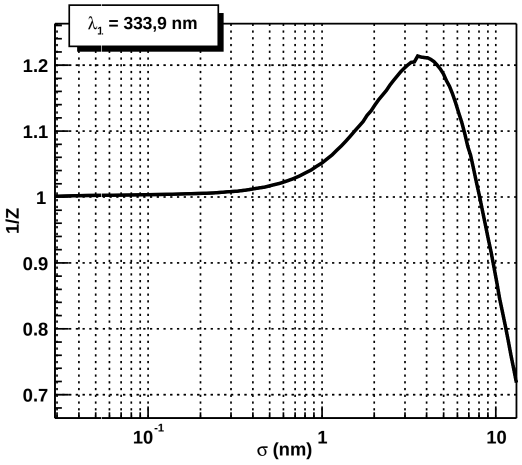
Rel. Error using eff. Transmission

< 7 %

Line Width

- **Photon rate can both increase and decrease**
- **ΔN ≈ 1 % for σ ≈ 0,3 nm.**
- **Example: Filter on previous transparency:**

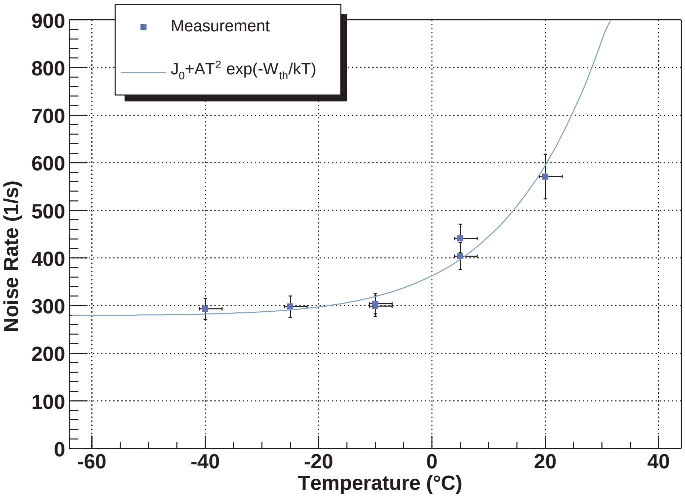




PMT Temperature Dependence

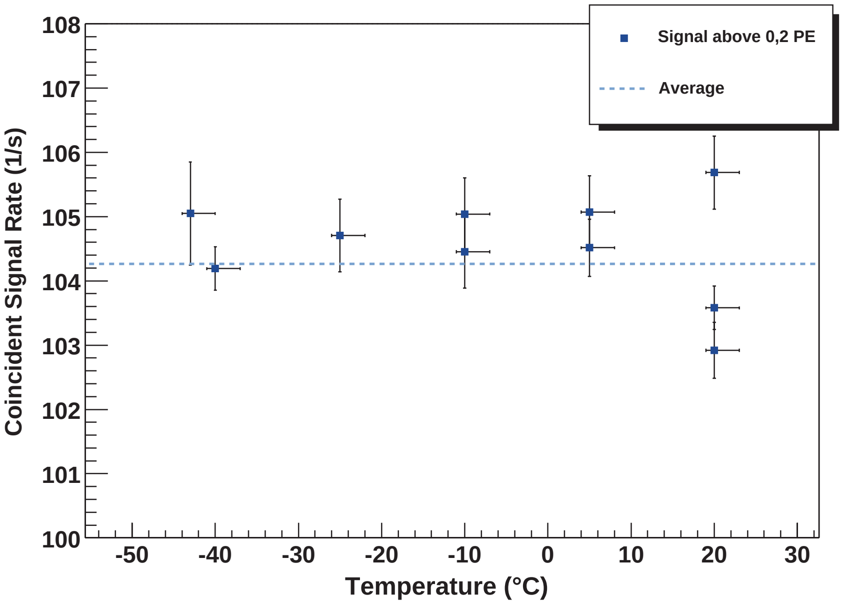
Noise Rate:

- $$\frac{dN}{dt} = J_0 + \underbrace{AT^2 \exp(-W_{th}/kT)}_{\text{Thermionic Emission}}$$
- ΔN ≈ 3 % per K @ 20°C



Efficiency:

- ~ constant
- σ = 0,8 %

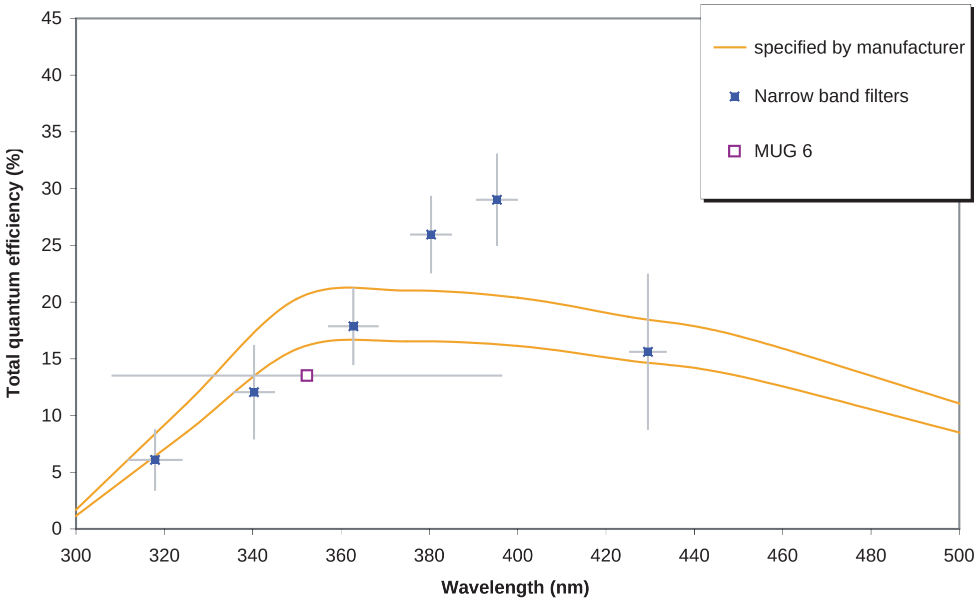


PMT Spectral Efficiency

Tot. QE: $$\boxed{\Gamma_{\text{tot}} = T_{\text{w}}(\lambda)\cdot \rho(\lambda)\cdot \eta(\lambda)}$$

- $T_{\text{w}}(\lambda)$ = Input window transmission < 93 %
- $\rho(\lambda)$ = Photocathode quantum efficiency < 30 %
- $\eta(\lambda)$ = Input system collection efficiency < 85 %

A Cherenkov light source was built and a calibration on one individual PMT was done with narrow band filters:



→ Individual PMT

≠ manufacturer's *mean* specifications!

Summary

- Interference Filters
  - Relative errors of the transmission values are reduced from > 20% to 7%.
  - This is achieved after evaluating effective transmission curves.
  - Averaging the transmission curves is possible after parameterising the measurements with two Gaussians.
- Photomultiplier Tubes
  - Temperature-altering measurements with PMTs are possible.
  - For absolute measurements, individual efficiency spectra of the PMT have to be measured.