Aalto University
School of Electrical
Engineering

Realization of Improved *Solar UV Diffusers*

Tomi Pulli[1], Josef Schreder[2], Allard Partosoebroto[3], Gregor Huelsen[4], Janne Askola[1], Joop Mes[3], Petri Kärhä[1,5], and Julian Gröbner[4]

1. Metrology Research Institute, Aalto University, Espoo, Finland
2. CMS - Ing. Dr. Schreder GmbH, Kirchbichl, Austria
3. Kipp & Zonen, Delft, Netherlands
4. Physikalisch-Meteorologisches Observatorium Davos PMOD/WRC, Davos, Switzerland
5. Centre for Metrology and Accreditation MIKES, Espoo, Finland

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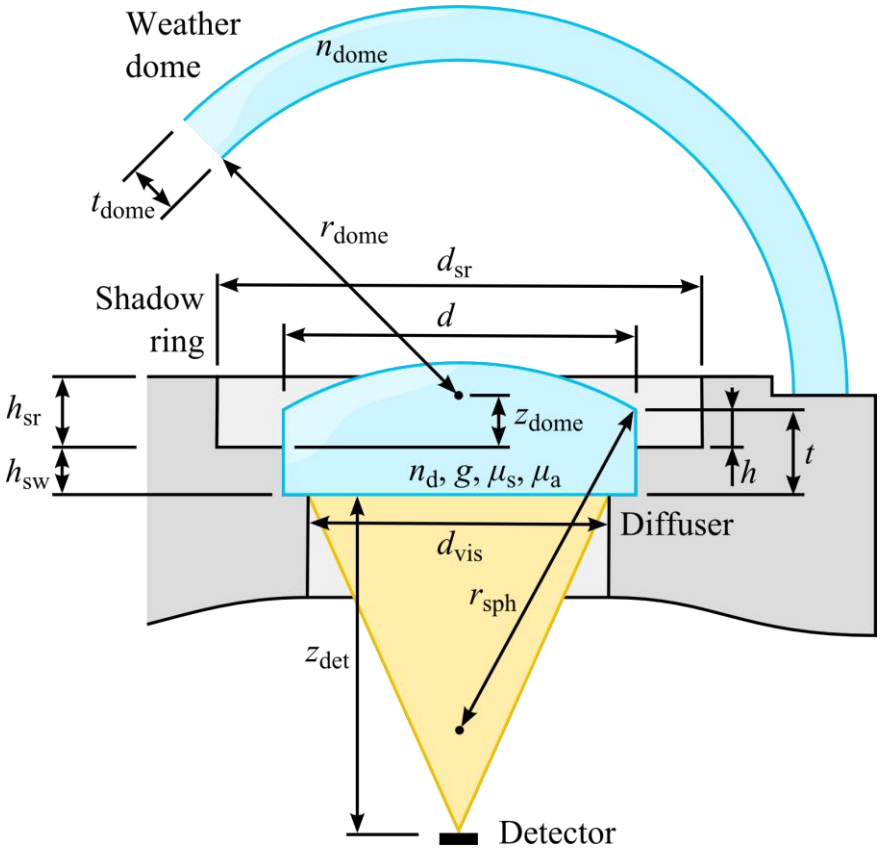
EMRP ENV03 SolarUV

Part of this work has been supported by the European Metrology Research Programme (EMRP) within the joint research project “Traceability for surface spectral solar ultraviolet radiation” (SolarUV). The EMRP is jointly funded by the EMRP participating countries within EURAMET and the European Union.

Background
Global UV irradiance measurement

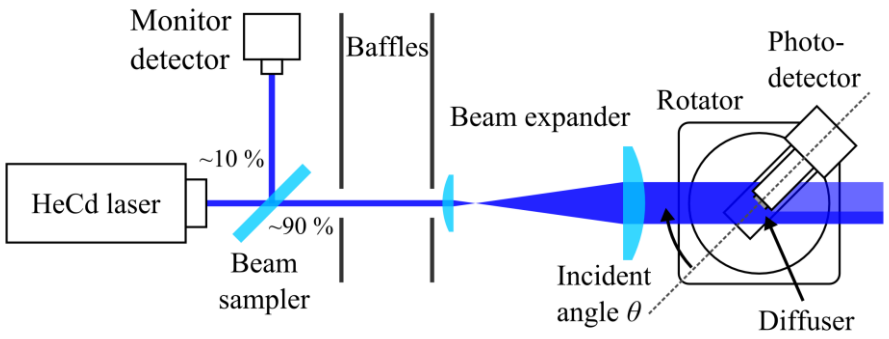
- ***Diffusers*** **used in global solar UV irradiance measurements.**
- **Angular response**
  - Proportional to the ***cosine of the zenith angle*** of radiation.
  - ***Independent of the azimuth angle***.
- **Purely trial-and-error based optimization is time consuming.**



Steps of *Diffuser optimization*

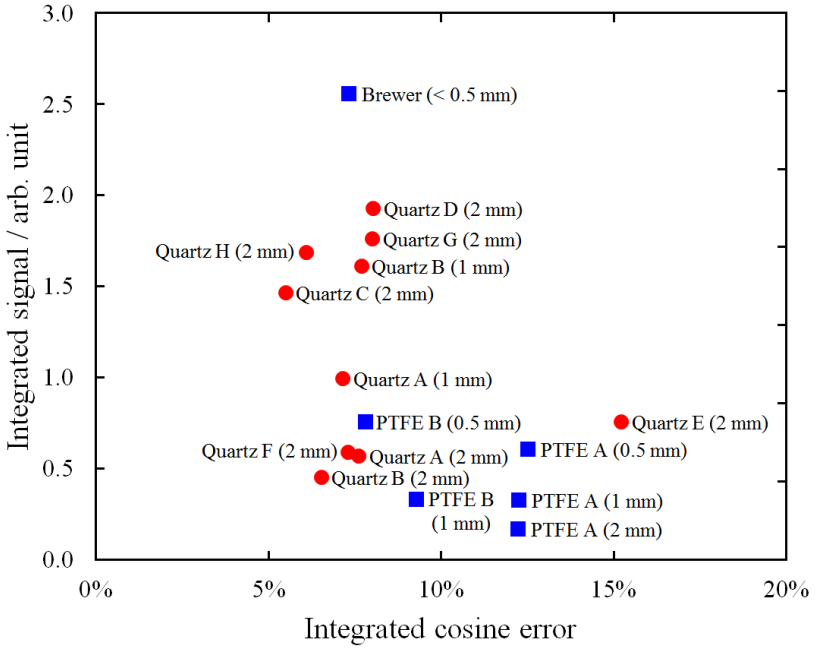
1. **Study different *diffuser materials.***
   - PTFE (Teflon) or quartz?
2. **Construct *simulation algorithm.***
   - Monte Carlo ray tracing
3. **Find out *material parameters.***
   - Compare measurement results with simulations
4. **Use algorithm to *optimize* diffuser geometry.**
5. ***Construct and characterize the diffuser.***

Material characterization
Angular response & transmittance



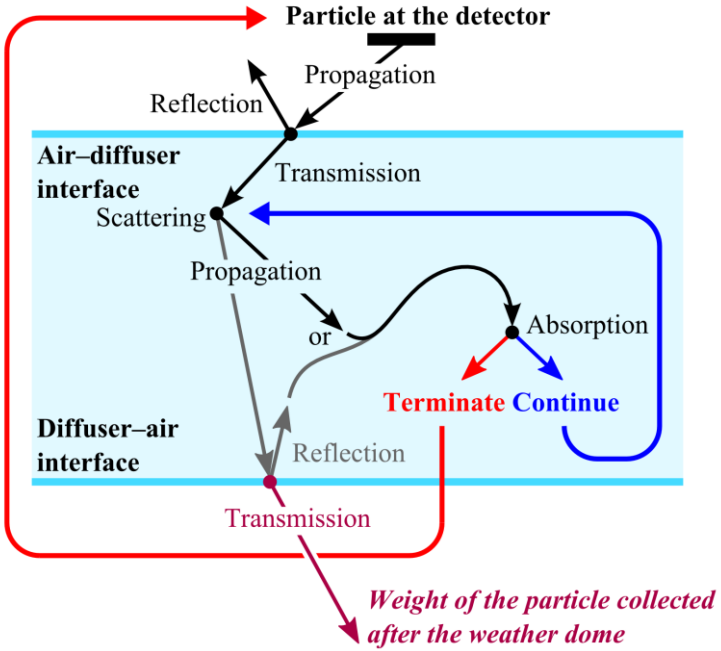
- **Beam-expanded HeCd gonio.**
- ***"Bubbled" quartz* materials***
  - No phase transition
  - High transmittance
  - Low integrated cosine error

$$f_2 = \int_{0^\circ}^{85^\circ} \left| \frac{R(\theta)}{R(0)\cos(\theta)} - 1 \right| \sin(2\theta) d\theta \cdot 100\ \%$$



* B. Barton, P. Sperfeld, S. Nowy, A. Towara, A. Höpe, S. Teichert, G. Hopfenmüller, M. Baer, and T. Kreuzberger, "Characterization of new optical diffusers used in high irradiance UV radiometers," Poster presented at NEWRAD 2011, Maui, Hawaii, September 19–23, 2011.

Diffuser algorithm
Overview

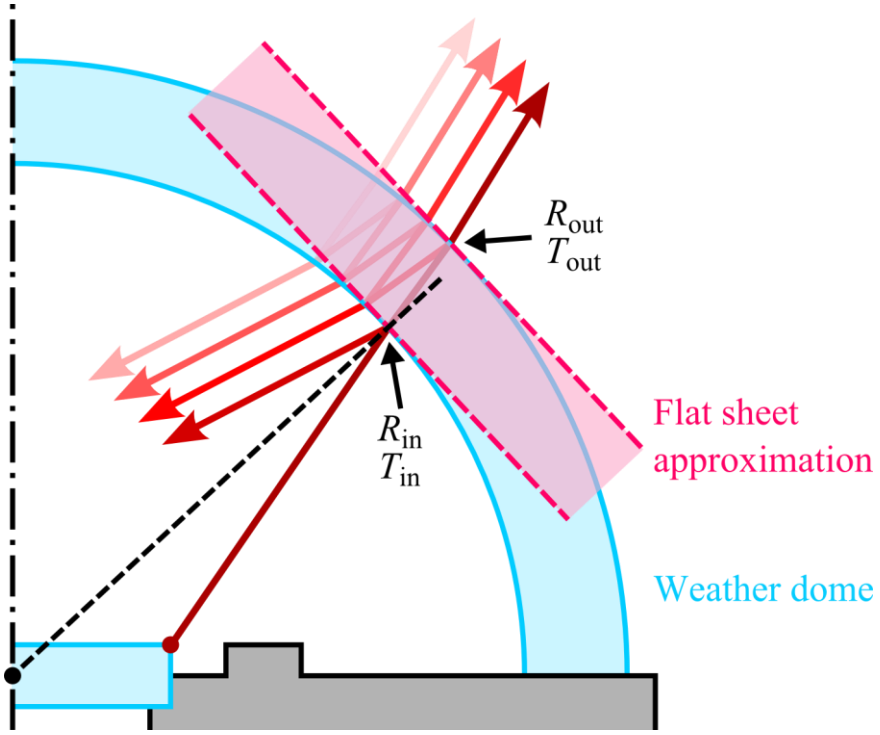


* T. Pulli, P. Kärhä, and E. Ikonen, "A method for optimizing the cosine response of solar UV diffusers," *J. Geophys. Res. Atmos.* **118**, 7897-7904 (2013).
** L. Wang, S. L. Jacques, and L. Zheng, "MCML — Monte Carlo modeling of light transport in multi-layered tissues," *Comput. Meth. Programs. Biomed.* **47**, 131–146 (1995).

- ***Monte Carlo ray tracing*** **algorithm.***
- **Rays traced from detector towards the sky.**
- **Inside the diffuser ****
  - Propagation
  - Scattering
  - Absorption
- **Material interfaces**
  - Transmission
  - Reflection

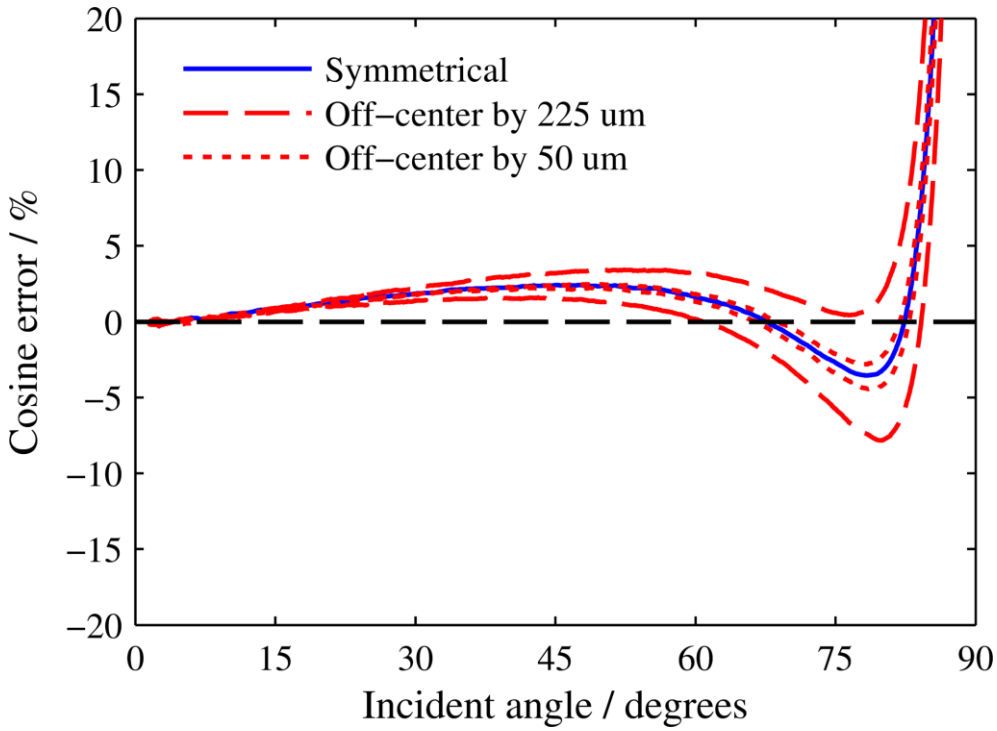
Diffuser algorithm
Weather dome

- Affects the *propagation direction* and *weight* of the particle.
- Angle of the first transmitted ray calculated exactly.
- Transmittance from *geometrical series* using flat sheet approximation.



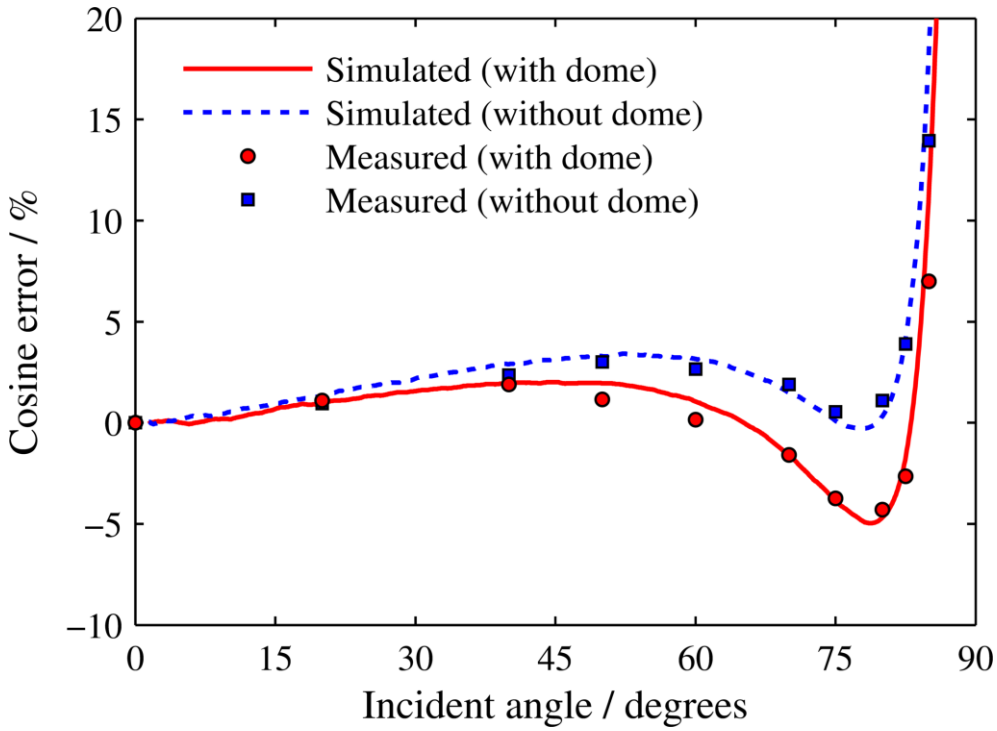
Simulation
Parameter sensitivity

- **The sensitivity of the angular response to different parameters can be studied.**
- **For example, studying the effect of spatial *misalignment of the diffuser element*.**
  - By changing the visible area of the diffuser.
  - Small manufacturing tolerances required!



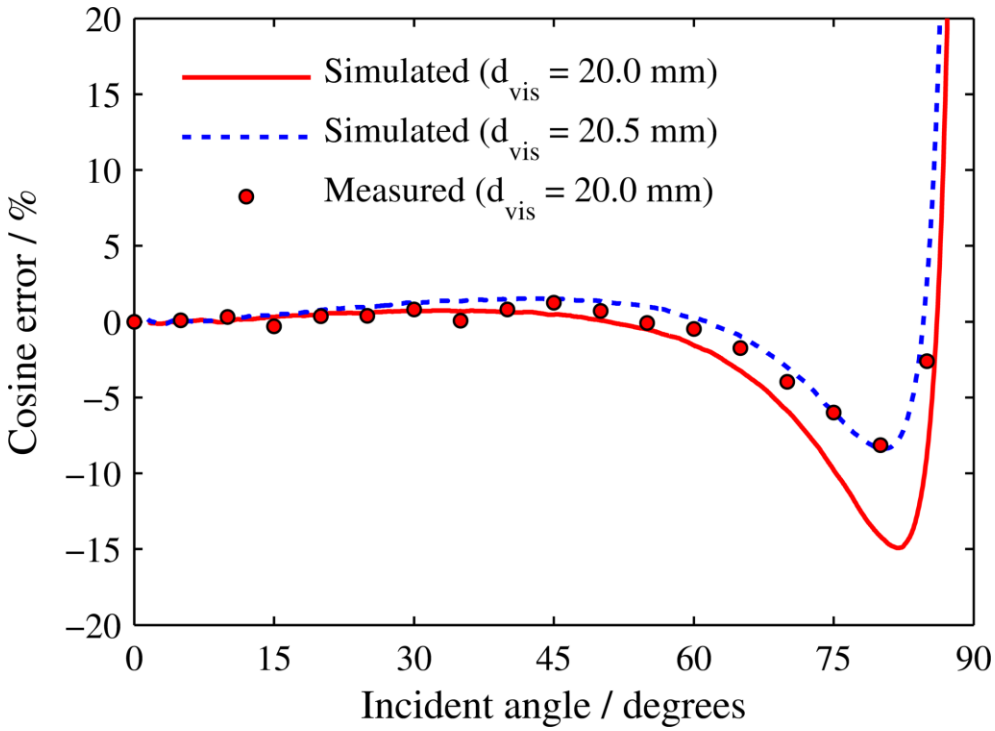
Optimized diffusers
Fiber diffuser (Schreder)

- ***Flat quartz diffuser***
  11 mm in diameter.
- **Integrated cosine error $f_2 = 1.4\ \%$.**
- **Simulation results agree after small modification**
  - Diameter of the visible area of the diffuser was decreased by 1.3 mm.
    - The angular response of the optical fiber was not characterized.



Optimized diffusers
Brewer diffuser

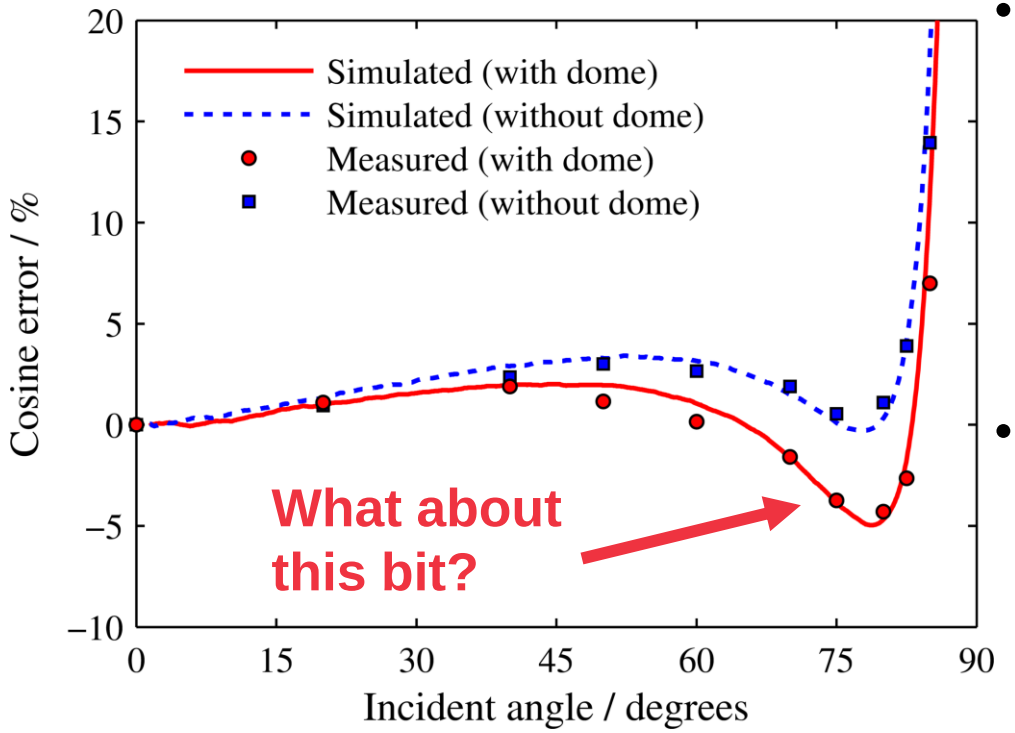
- ***Flat quartz diffuser*** **22 mm in diameter.**
- **Integrated cosine error $f_2 = 1.3\ \%$.**
  - Significant improvement over the standard diffuser!
- **More on this in the talk by Allard and Joop.**



Realization of Improved UV Diffusers
Conclusions

- ***Monte Carlo algorithm*** **for optimizing solar UV diffusers was developed.**
  - Can guide the diffuser design process.
  - Useful for parameter studies (manufacturing tolerances!)
- ***"Bubbled" quartz diffusers*** **have variety of attractive features.**
  - Transmittance, angular response, no phase transition, etc.
- ***Two new of entrance optics*** **were constructed in the project.**
  - Simple planar quartz diffuser elements.
  - Measured integrated cosine error around 1.4 %.

Outlook
or how to proceed?



- **Surface roughness?**
  - Alters the angular response at large incident angles.
  - Potential problems
    - *Azimuthal dependence*
    - *Harder to simulate*
- **Shaped diffusers?**
  - E.g. Spherical front surface.
  - Potential problems
    - *Manufacturing cost, quality and tolerances.*