LED near-field goniophotometer at PTB

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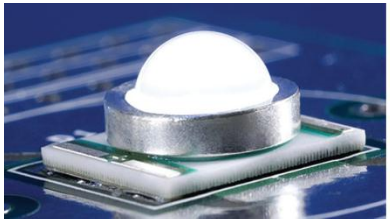
Motivation



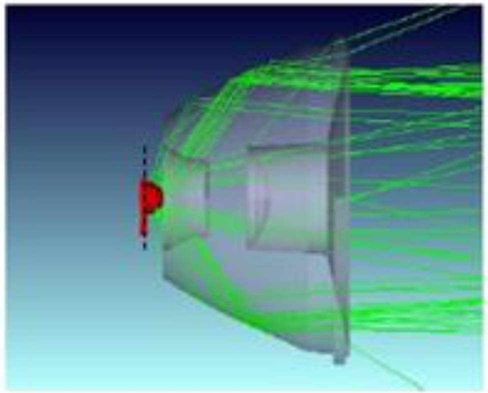
• LEDs are employed today in a great variety of applications:

⇒ Lighting, Traffic signal, Automotive, Medical lighting, etc.

• The small size of the LEDs allows to design high quality of lighting systems by using optical design software.

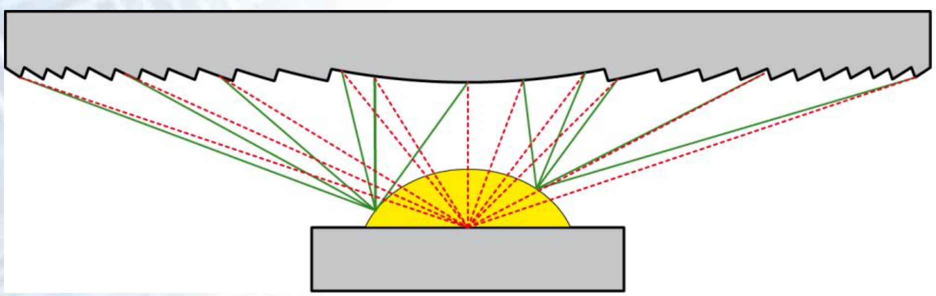
• For optical simulations, the complete distribution of the optical radiation of a light source is required (near-field model).

• Traceability of near-field goniophotometric measurements is still missing!!

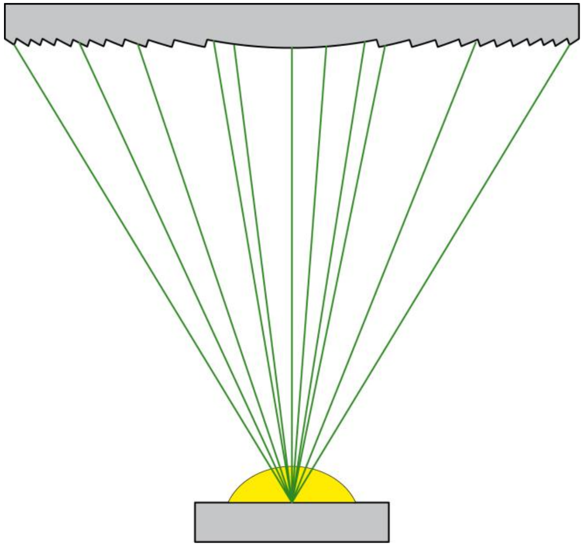


Comparison of a near- and a far- field distribution

- The abstraction of a light source, e.g. a LED, as a point source causes errors in the simulation by designing optical devices
- These errors are relevant when the optic element is placed near to the LED, e.g.
  - by the design of refractive and diffractive optic elements, fiber optic coupling systems, etc.

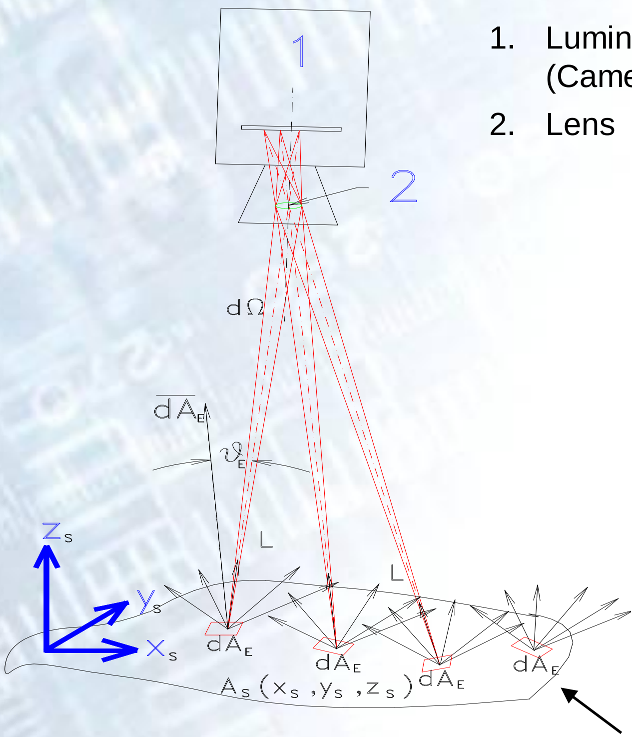


Near field distribution



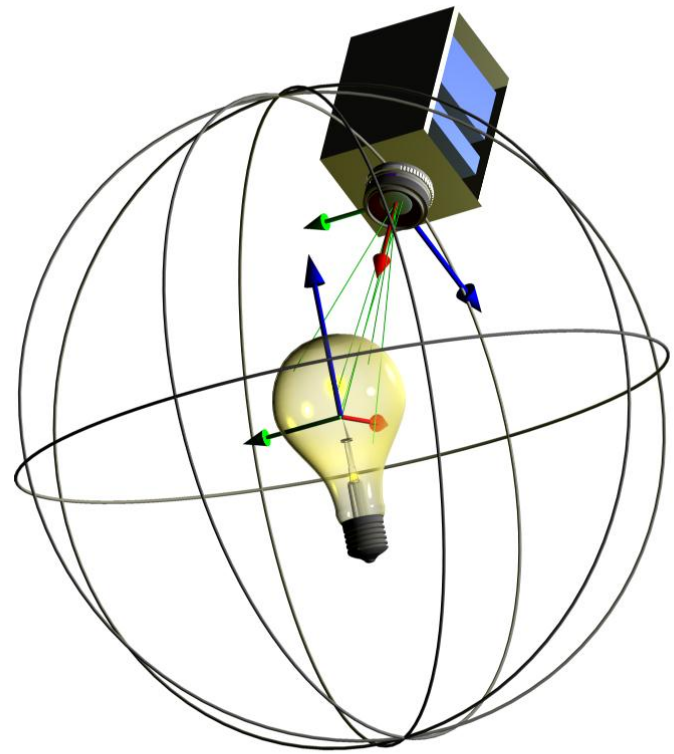
Far field distribution

Near-field goniophotometer



1. Luminance Meter (Camera)
2. Lens

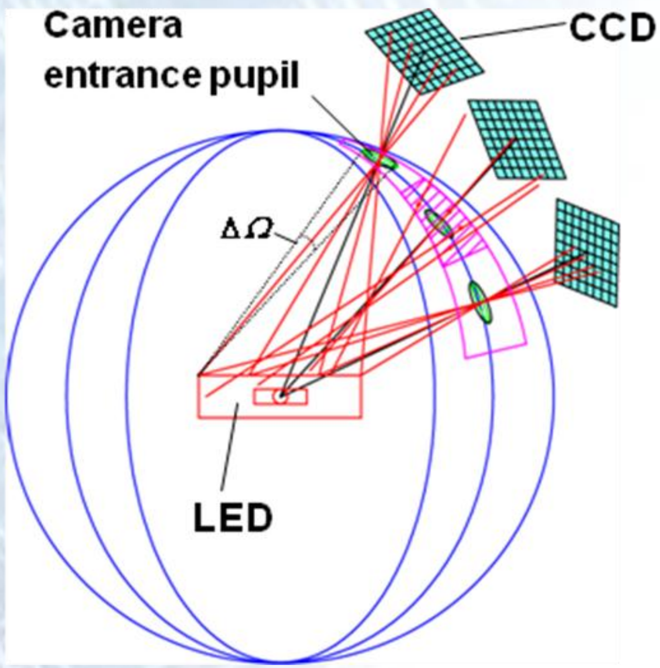
Luminance distribution

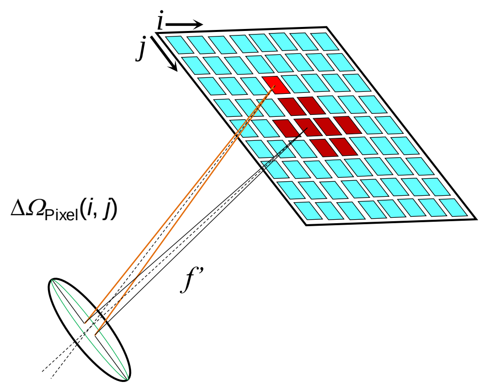


$$L_v(\vartheta_E, \varphi_E) = \frac{d\Phi_v}{dA_E \cdot \cos\vartheta_E \cdot d\Omega(\vartheta_E, \varphi_E)}$$ [cd/m²]

A near-field goniophotometer measures the luminance distribution of a light source from all light-emitting directions by using a luminance camera.

Principle of a near-field goniophotometric measurement



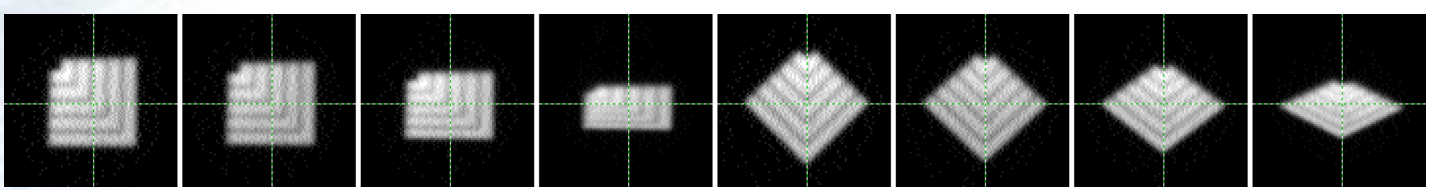


- A luminance measuring camera (CCD) is moved around the measuring object carrying out several luminance images

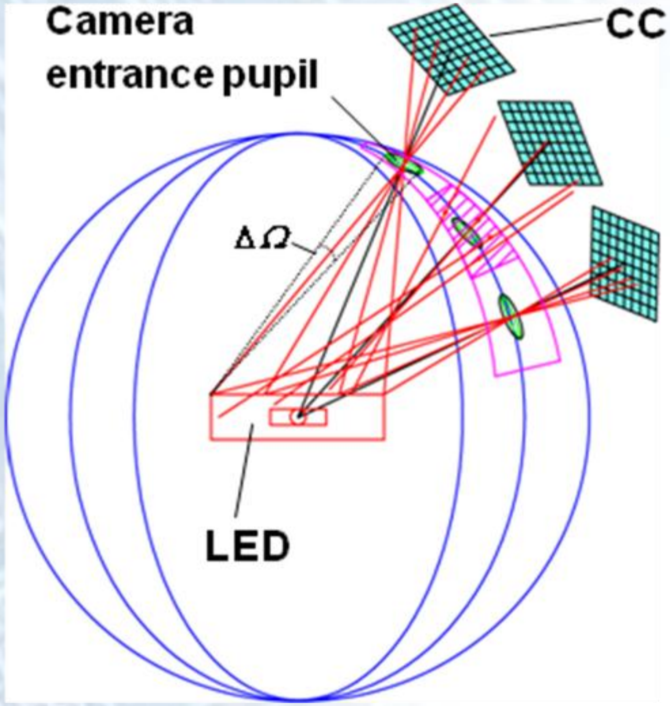
$$L_i(x_D, y_D, z_D, \vartheta_C, \varphi_C)$$

- Pixels of the CCD sensor can be regarded as small single sensors
- Area of each pixel represents a very small solid angle $\Delta\Omega(i,j)$
- Luminous flux captured by a pixel can be calculated as:

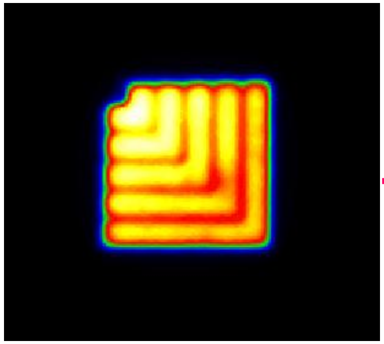
$$\Delta\Phi_{ij}(x,y,z,\vartheta,\varphi) = L(x,y,z,\vartheta,\varphi)\cdot\Delta\Omega_j(\vartheta,\varphi)\cdot\cos\vartheta\ \cdot\Delta A_i(x,y,z)$$



Near-field Goniophotometer



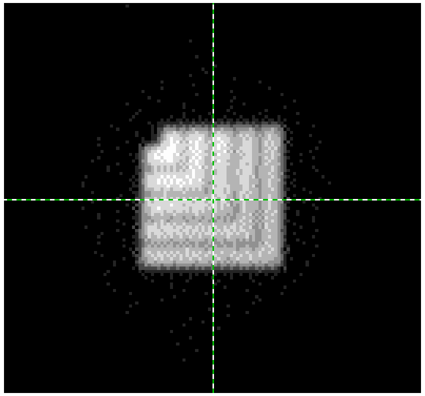
Luminance image



Luminance values to luminouse flux portions

$$\Delta\Phi(i,j) = L(i,j)\cdot c\cdot\Delta\Omega(i,j)$$

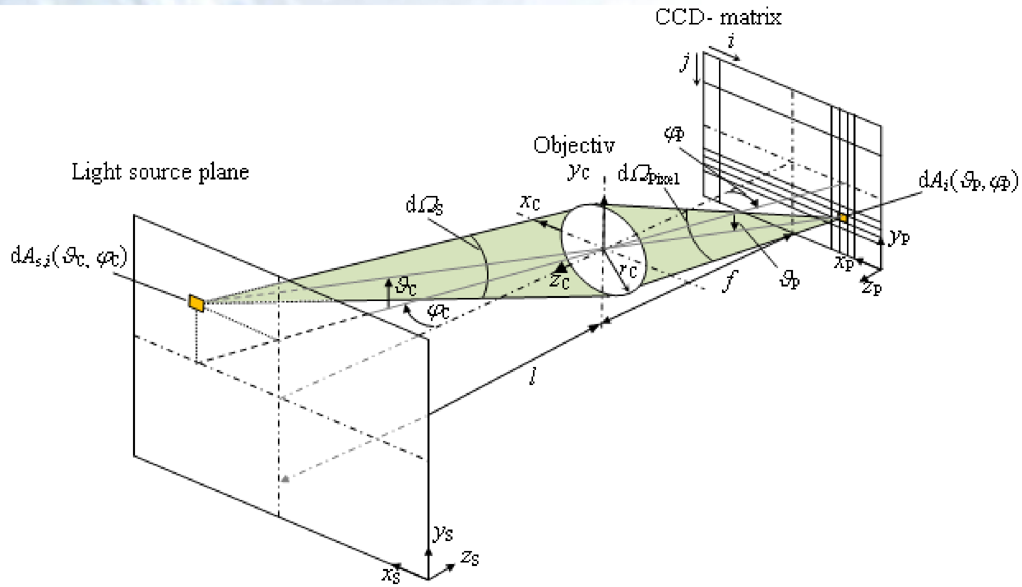
Extracted rays (23000 rays per image)

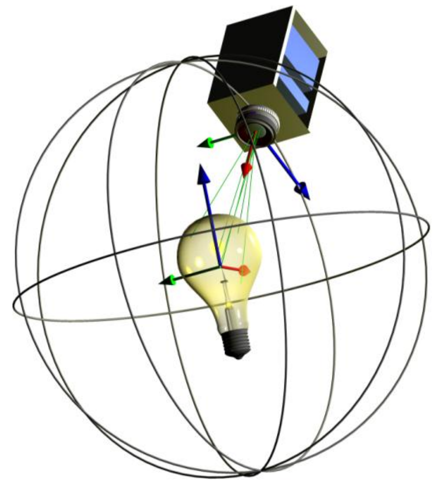


- Multiplication of each luminance pixel with is corresponding solid angle
- Extraction of rays (compression to approx. 23000 per image)

Calculation of “ray data”

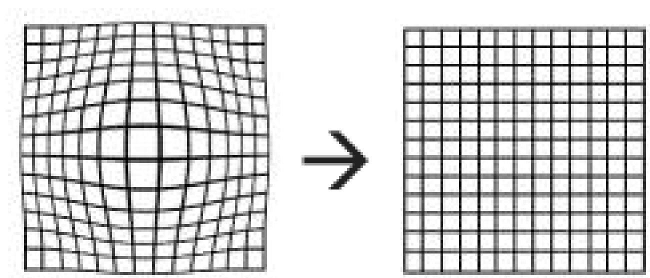
• With the exact knowledge of the optical imaging system (lens) the “direction of light” from each pixel can be calculated.





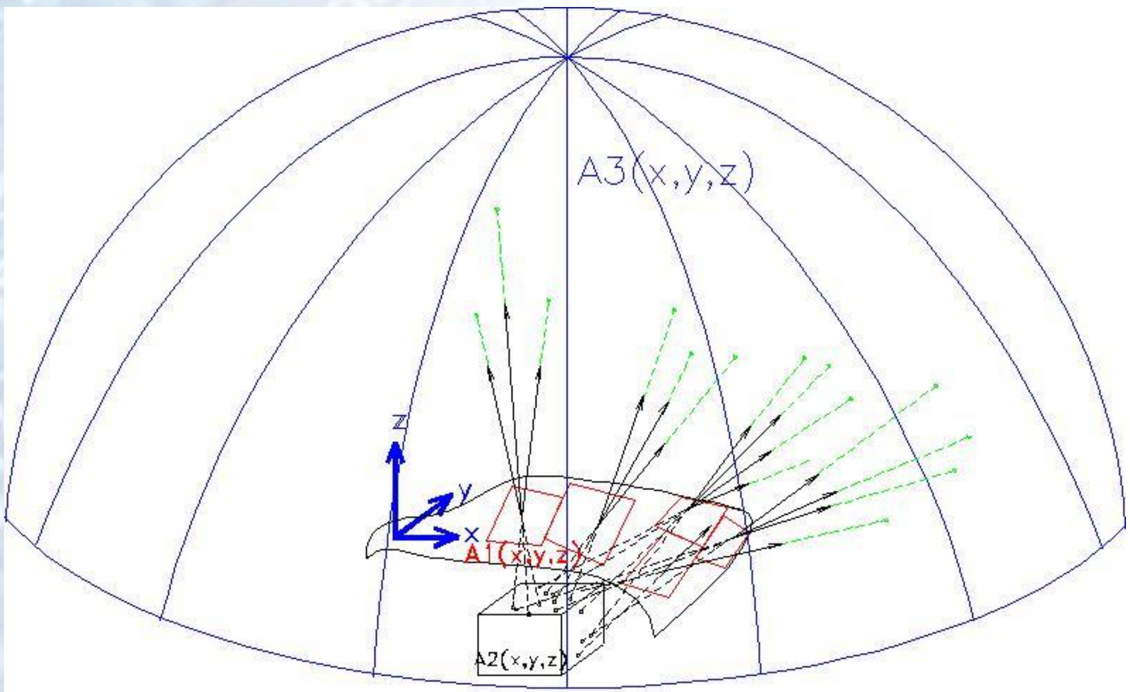
$$\vartheta_C(i,\ j) = \arctan\left(\frac{\sqrt{x^2 + y^2}}{f'}\right) = \arctan\left(\frac{\sqrt{(i \cdot \Delta x_{\mathrm{Pixel}})^2 + (j \cdot \Delta y_{\mathrm{Pixel}})^2}}{F}\right)$$

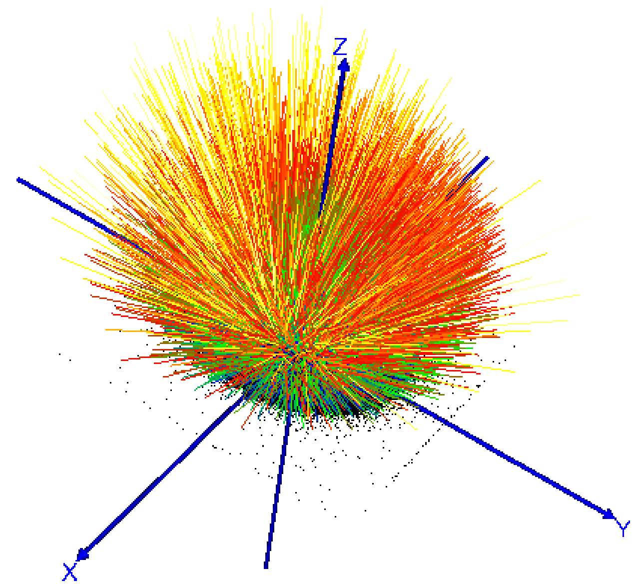
$$\varphi_C(i,\ j) = \arctan\left(\frac{y}{x}\right) = \arctan\left(\frac{j \cdot \Delta y_{\mathrm{Pixel}}}{i \cdot \Delta x_{\mathrm{Pixel}}}\right)$$



Objective distortion must be corrected!

Forward tracing of vectors calculated at the addendum envelopes A1 to A3 (green dashed) or back tracing at the real surface A2 (black dashed)





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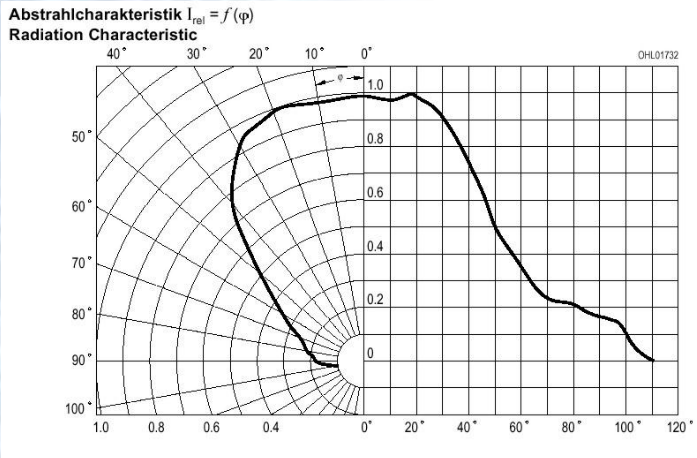
Luminous intensity distributions:

$$I(\vartheta_S,\varphi_S)=\int_A L(x_S,y_S,z_S,\vartheta_S,\varphi_S)\,dA_P$$

$$I(\vartheta_k,\varphi_l)=\frac{\sum_{x,y,z}\Delta\Phi(x_S,y_S,z_S,\vartheta_S,\varphi_S)}{\Delta\Omega(\vartheta_k,\varphi_l)}\quad\forall\,\vartheta_S,\varphi_S\in\Delta\Omega(\vartheta_k,\varphi_l)$$

All rays going in one direction (solid angle) are summed up (discrete notation).



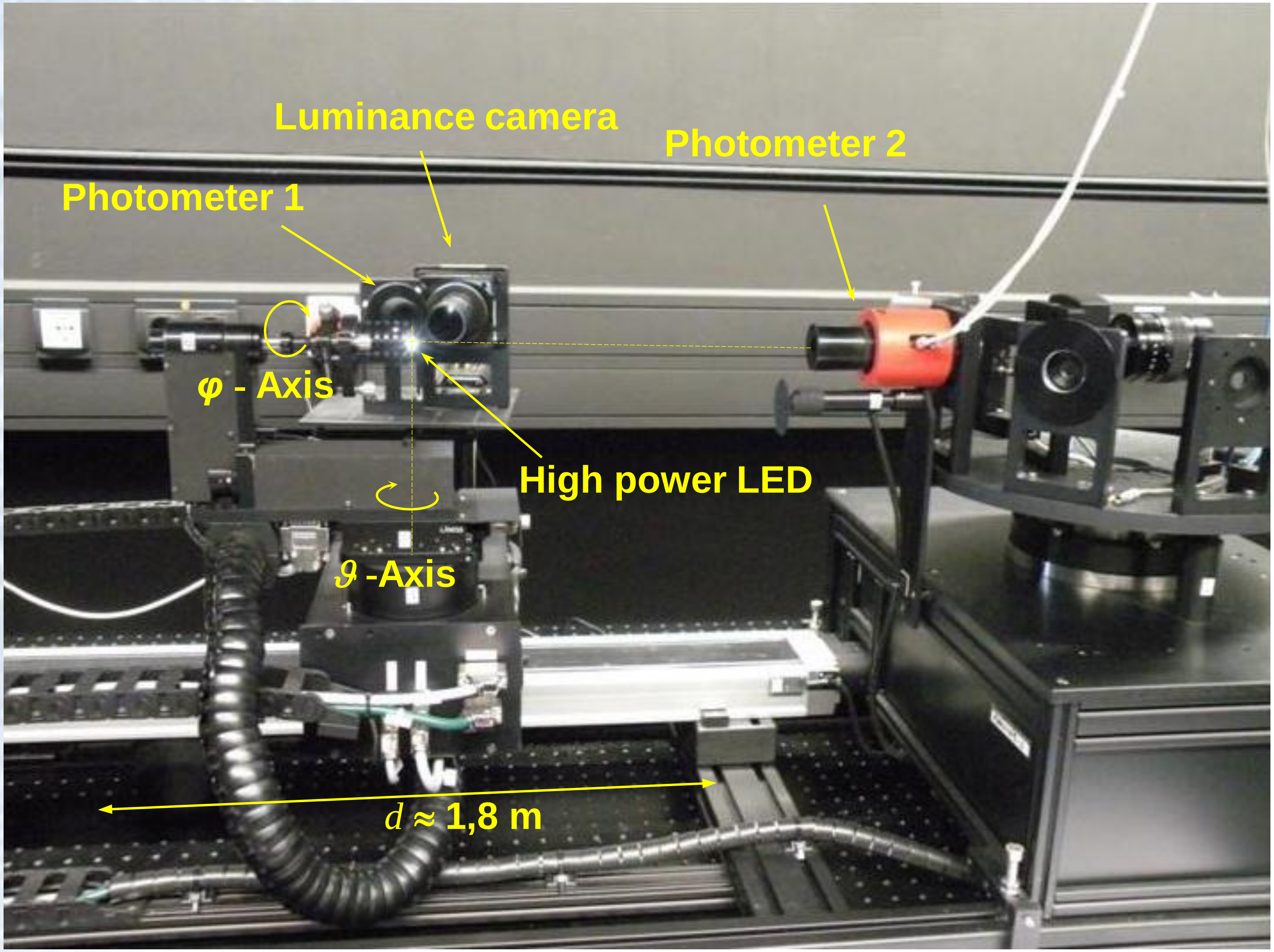
Total luminous flux:

$$\Phi=\iint_{A,\Omega} L(x,y,z,\vartheta,\varphi)\cdot dA\cdot\cos\vartheta\cdot d\Omega$$

$$\Phi=\sum_{x_S,y_S,z_S}\sum_{\vartheta_S,\varphi_S}\Delta\Phi(x_S,y_S,z_S,\vartheta_S,\varphi_S)$$

LED Far- and near- field goniophotometer at PTB

PTB

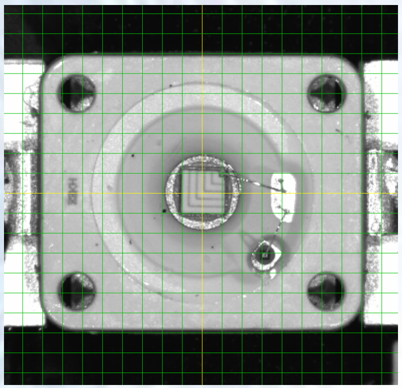


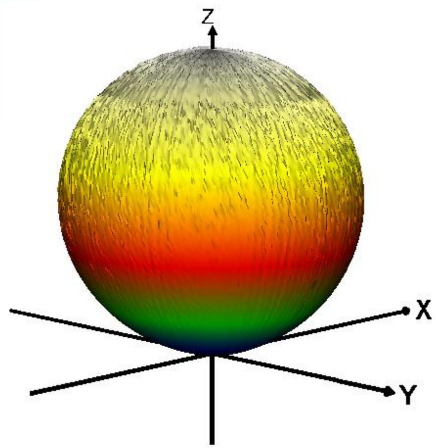
•Luminous intensity distribution from „Ray-Data“

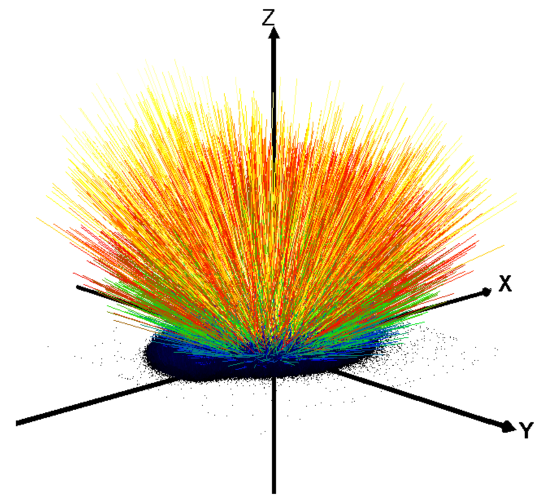
Camera picture

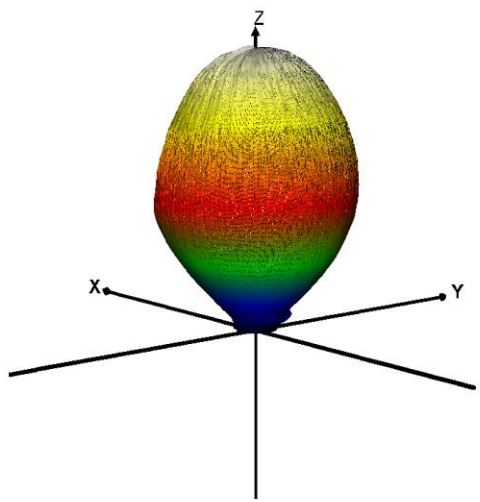
Luminous intensity distribution

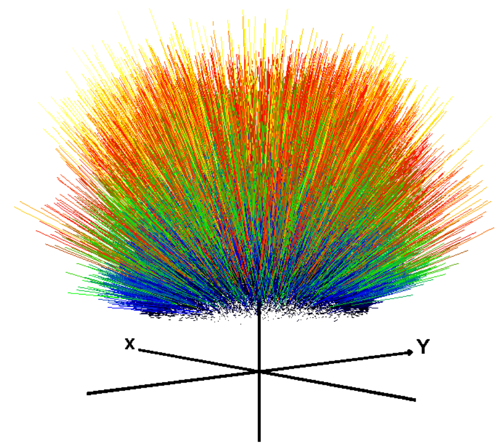
Rays distribution representation





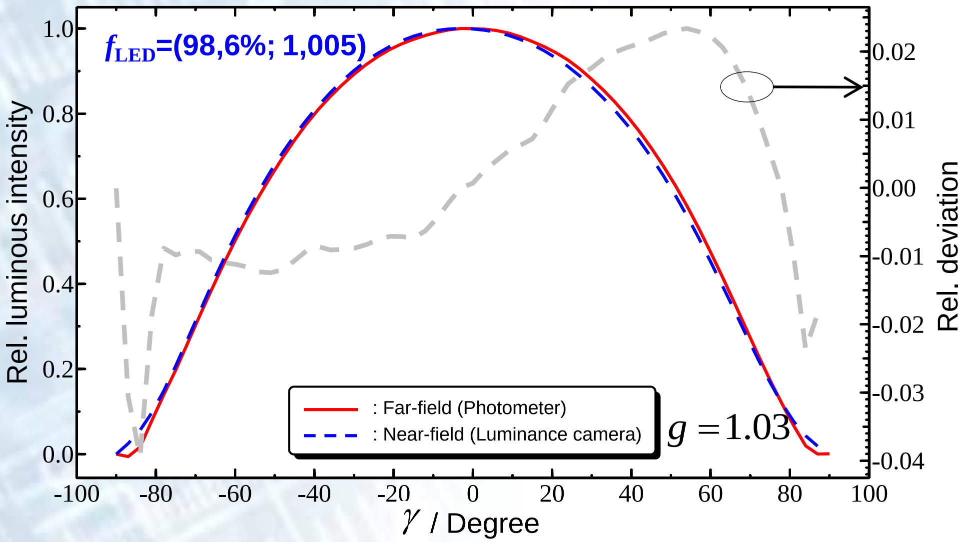


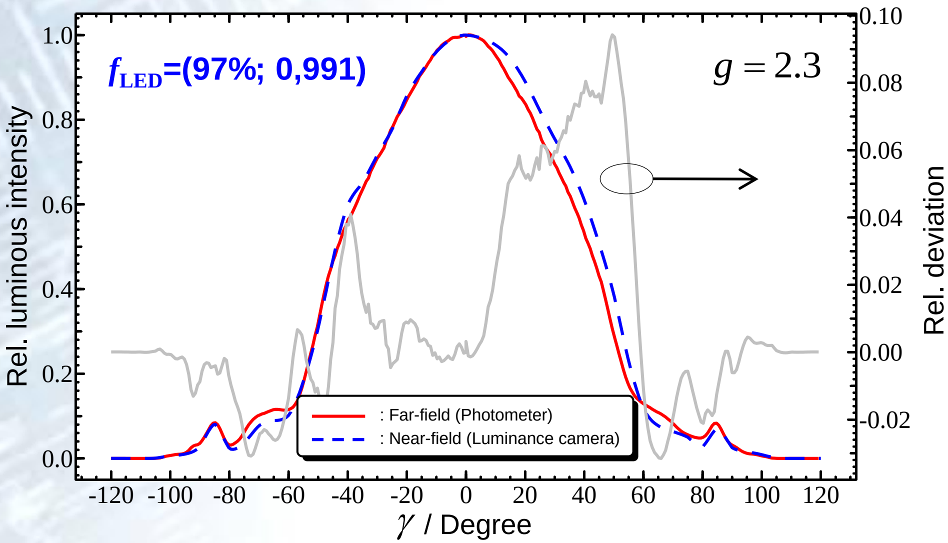




Comparison of luminous intensity distributions (Far- and Near- field)

PTB





***) Quality indices:**

$$f_{LED} = (f_{distribution,fit};\ f_{flux,fit}) \xrightarrow{\text{Identical distributions}} (100\,\%;1)$$

$$f_{distribution,fit} = 100 \cdot \left(1 - \frac{\sum_{C=0°}^{360°} \sum_{\gamma=0°}^{180°} \left(I_1(C,\gamma) - I_2(C,\gamma)\right)^2}{\sum_{C=0°}^{360°} \sum_{\gamma=0°}^{180°} \left(I_1(C,\gamma) + I_2(C,\gamma)\right)^2} \right)$$

$$f_{flux,fit} = \frac{\Phi_{V,1}}{\Phi_{V,2}}$$

$I_1(C,\gamma), I_2(C,\gamma)$: Luminous intensity distribution 1 and 2 at angle (C,γ).

$\Phi_{V,1}, \Phi_{V,2}$: Luminous flux calculated from distribution 1 and 2.

Lambertian emitter:

$$I_V(\vartheta) = I_0 \cdot Cos^g(\vartheta)$$

*) Bergen, A.S.J.,"A practical method of comparing luminous intensity distributions", CIE 27th Session, Sun City South Africa,

Summary and future works

PTB

Summary:

- The near-field goniophotometer setup established at PTB to measure LEDs under near-field conditions has been presented.

- The values of the luminous intensity distribution of two LEDs obtained by near-field measurements were compared to goniophotometric measurements carried out separately under far-field conditions using a photometer. The maximal average deviation obtained is ≤ 4%.

Future works:

- Evaluation of the measurement uncertainty (Model).
- Development of transfer standards for near-field measurements.
- Ray-data depending on the wavelength.
- Comparing ray-data?

...Thank you for your attention

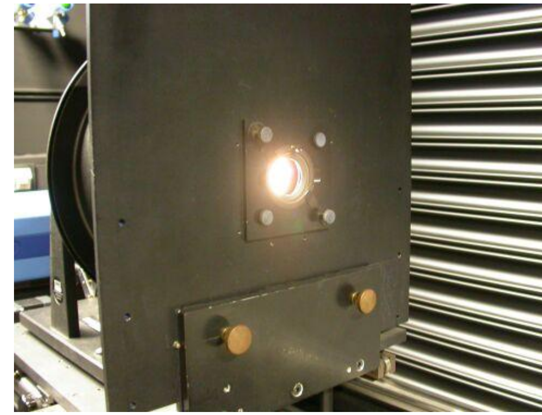
Traceability of the Luminance

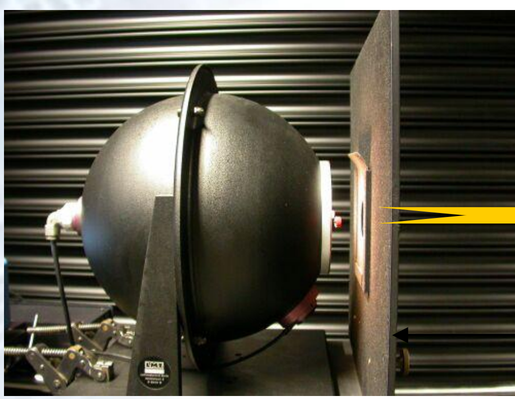
a) by means of the luminous intensity and a reference aperture A_1

$$L_\mathrm{m} = \frac{I_\mathrm{v}}{A_1}$$

Average luminance on the aperture area

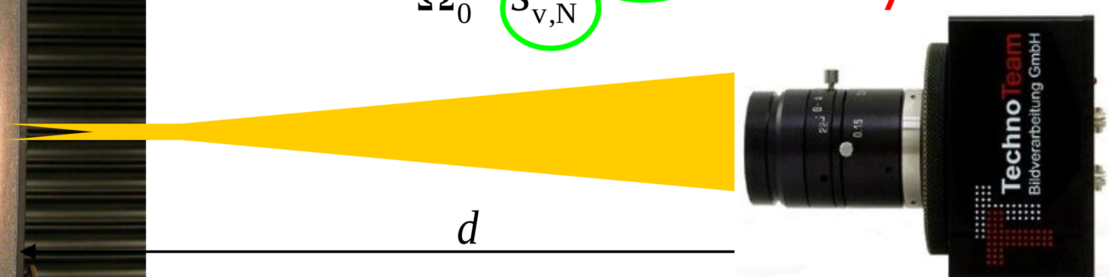
Unit: cd/m²



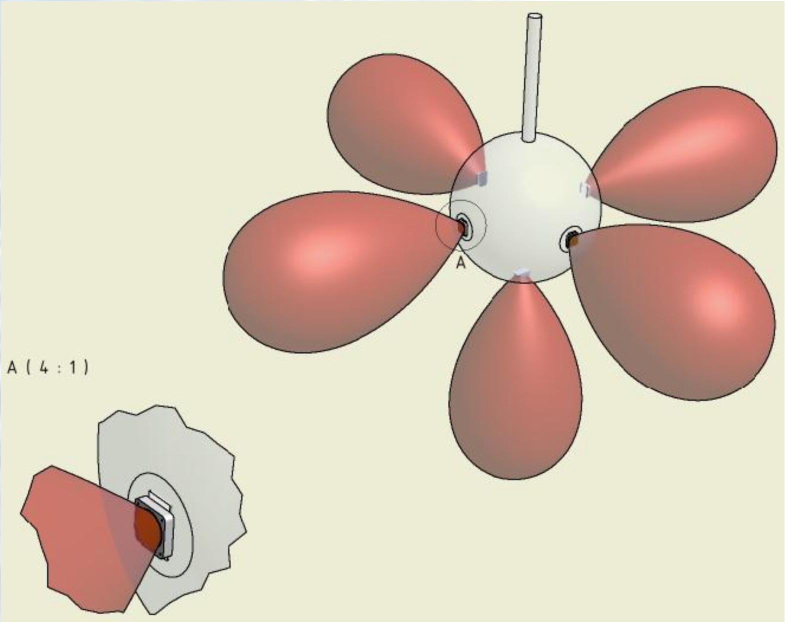


$$I_{\mathrm{v},i}\left(T_{\mathrm{v},i}\right) = \frac{d^2}{\Omega_0} \cdot \frac{y_i}{s_{\mathrm{v,N}}} \cdot F(T)$$

y_i

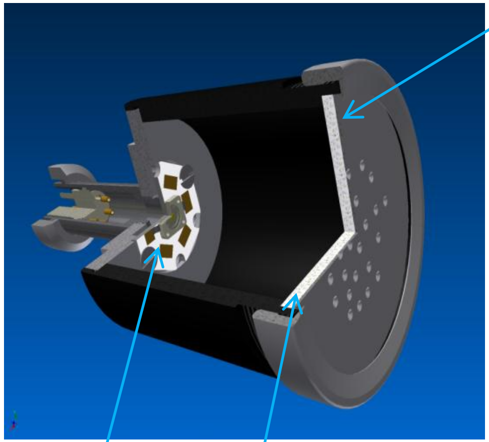


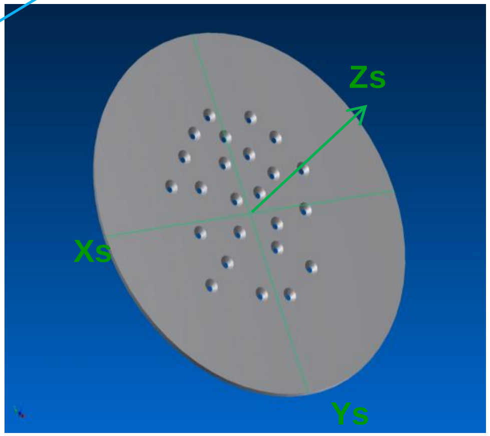
- Transfer standard for the luminous intensity distribution



- Transfer standard for the starting position of the ray data

Reference mask with precision apertures





LED

Diffusor

Defined area elements ΔAs, Position (x,y,z) and Coordinate system