

Experimental ray tracing for characterization of optical components

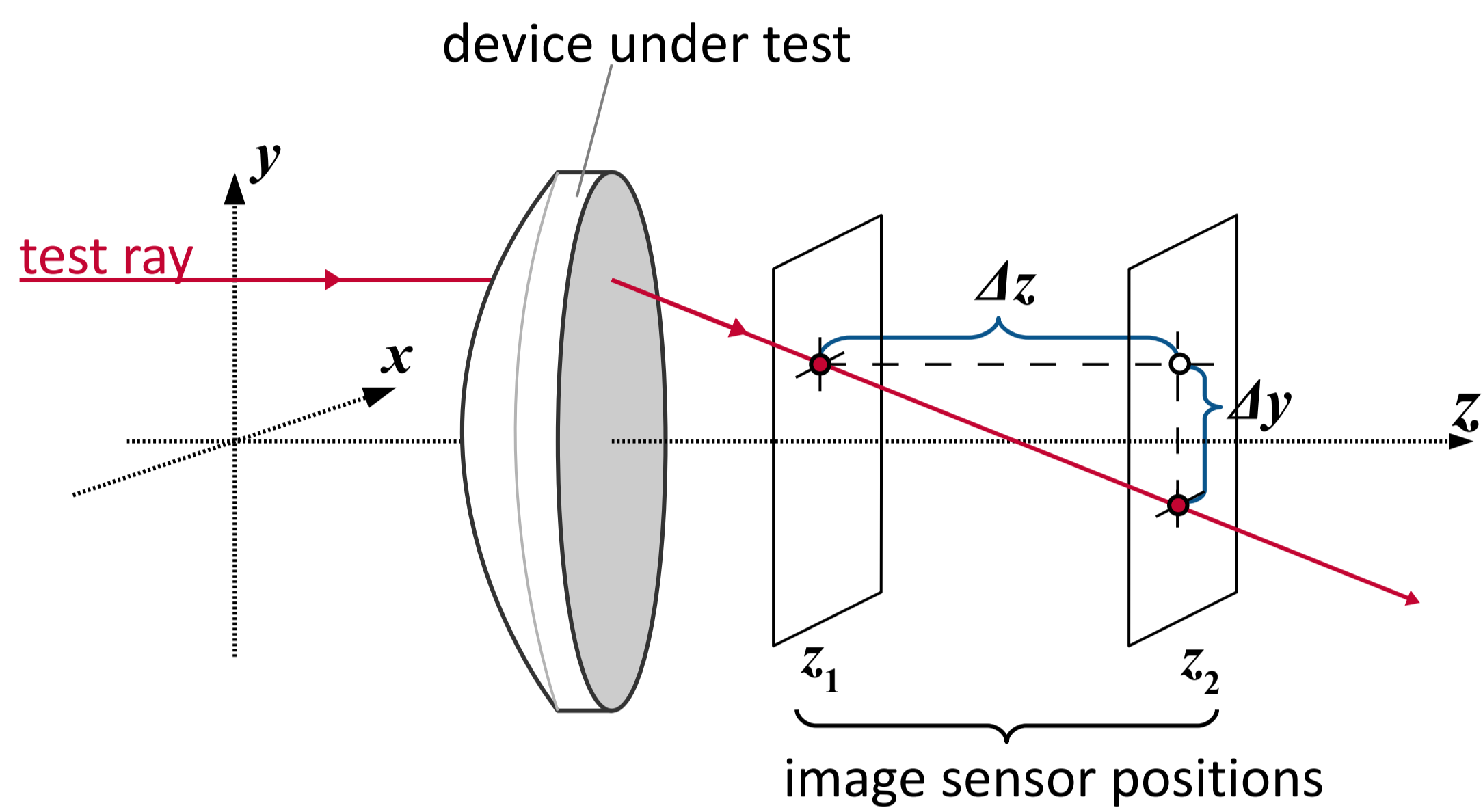
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ABSTRACT

We demonstrate a unique measurement principle capable of characterizing various optical components and systems with respect to diverse properties. The reachable precision is able to compete with the techniques available. Furthermore, it enables the verification of optical parameters that could not be measured before.

THE PRINCIPLE: EXPERIMENTAL RAYTRACING

Real-life implementation of traditional design principle from Geometrical Optics



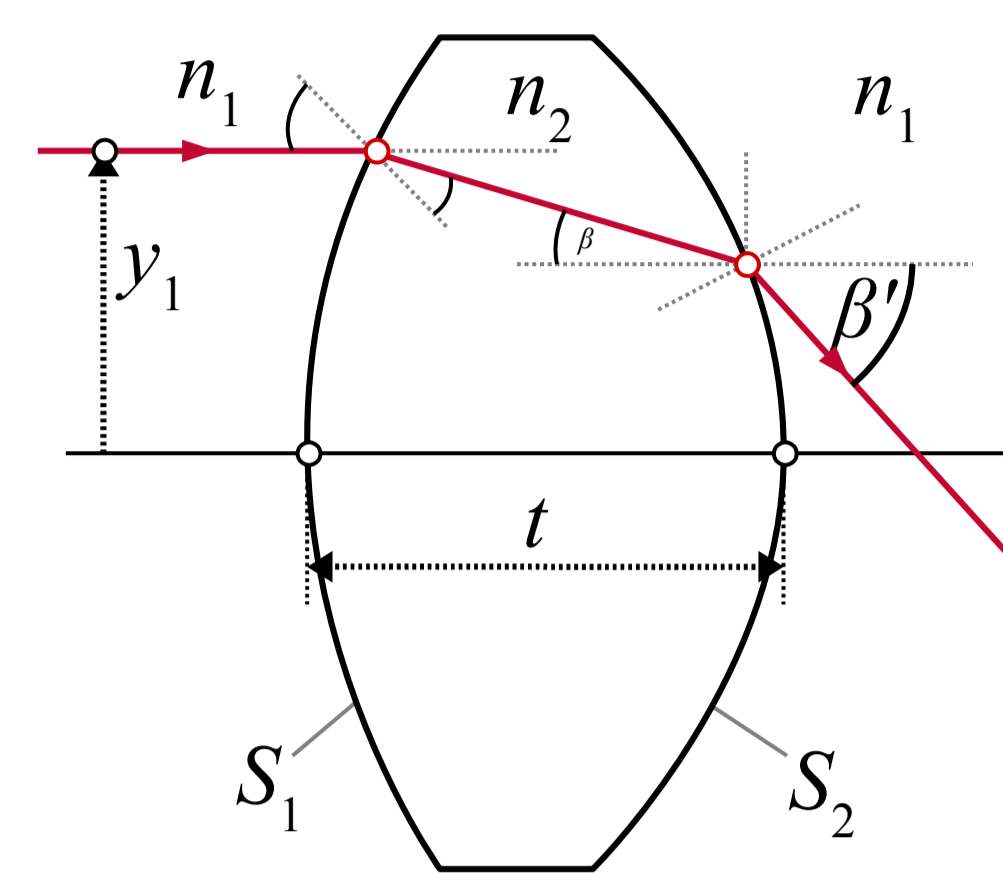
- scanning specimen with light beam along x, y
- detection of centroids in 2 planes z_1, z_2

ray slopes:

$$T_x = \frac{\Delta x}{\Delta z} = \frac{S_{x,2} - S_{x,1}}{z_2 - z_1}$$

$$T_y = \frac{\Delta y}{\Delta z} = \frac{S_{y,2} - S_{y,1}}{z_2 - z_1}$$

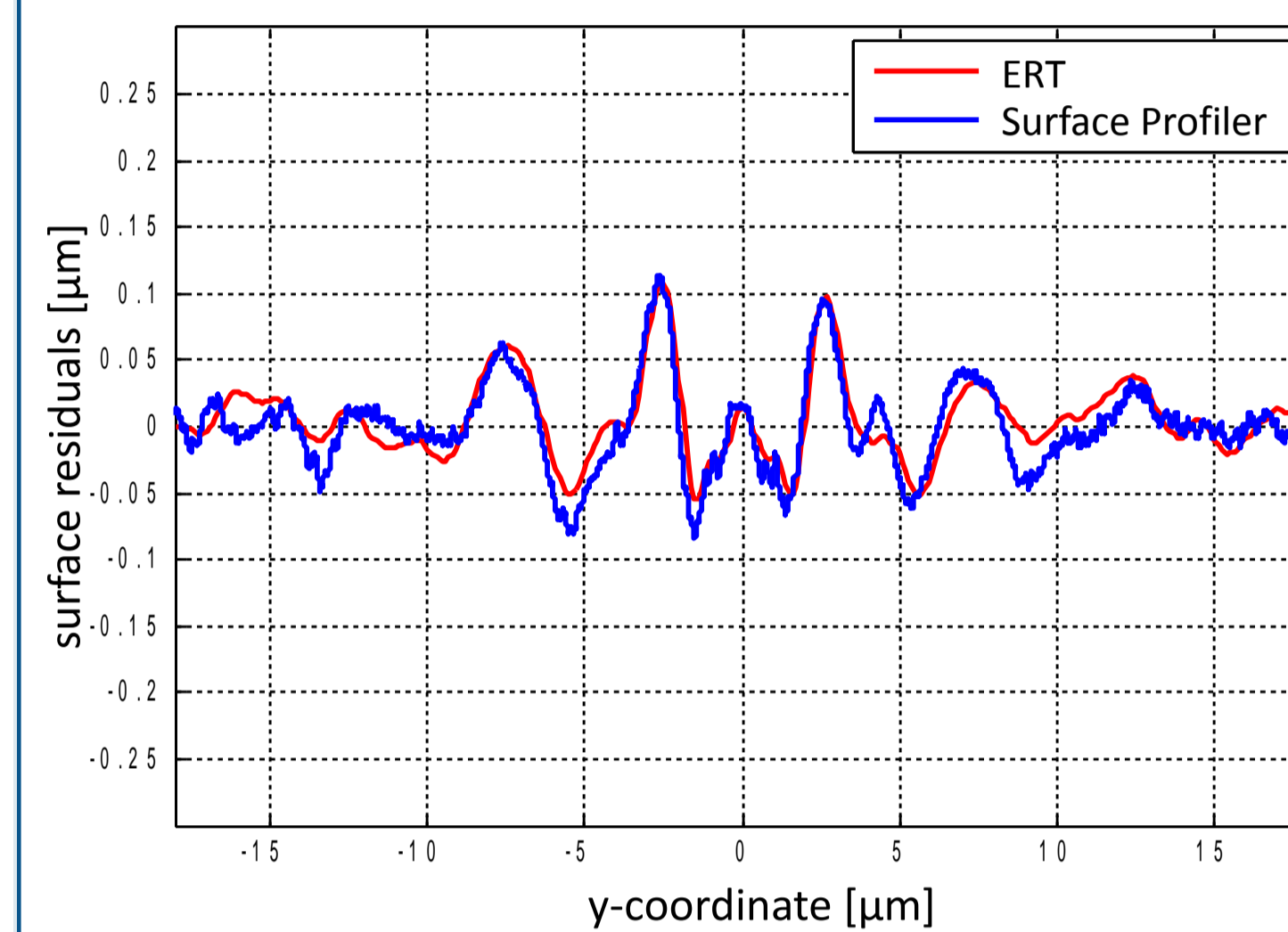
ASPHERICAL SURFACE RECONSTRUCTION



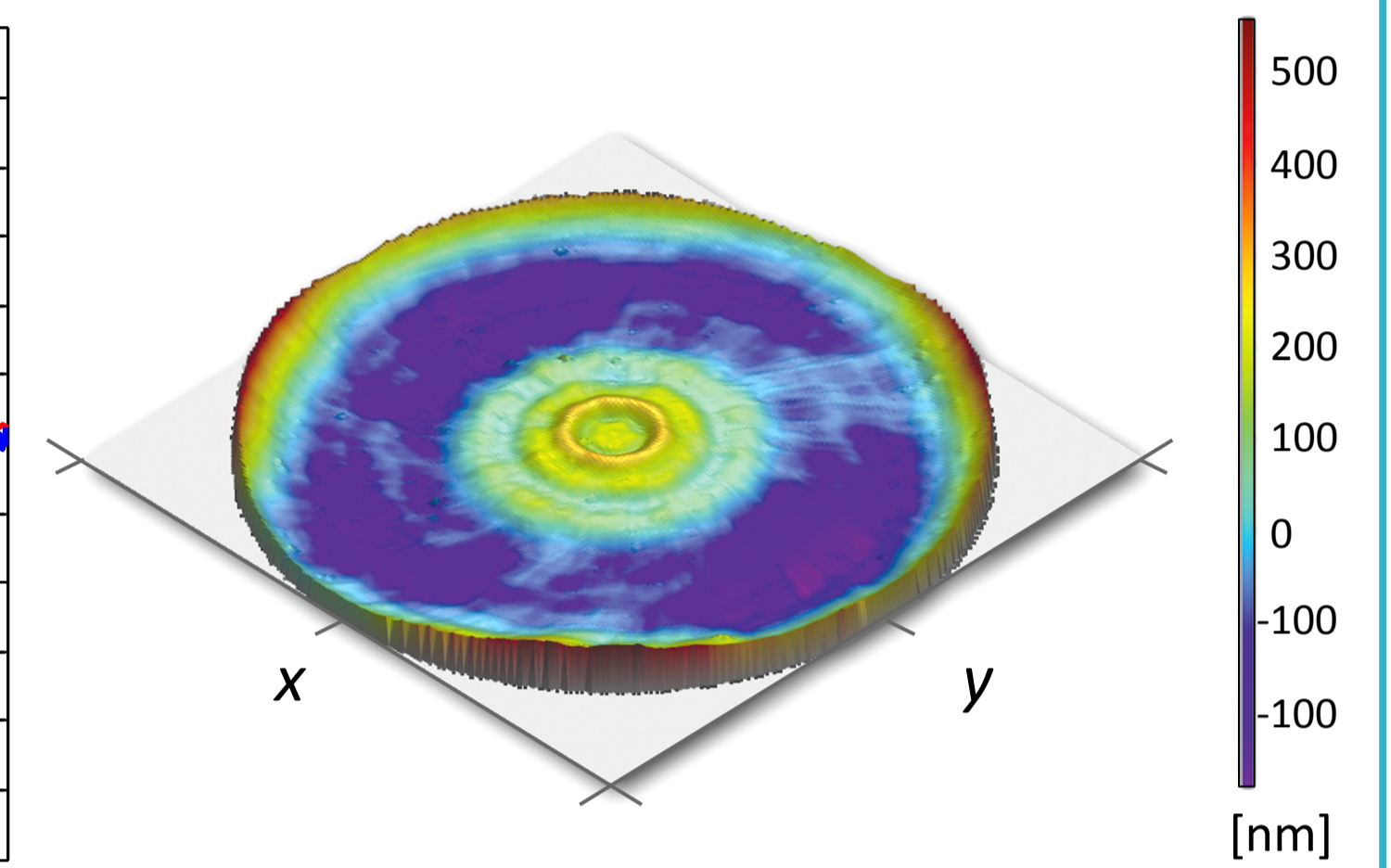
- known:
- position of input beam y_1
 - angle(slope) of outgoing beam
- condition:
- 2nd surface = plane or spherical
- assumption:
- R_2, n_2, t sufficiently known

non-linear optimizer

comparison to surface profiler:

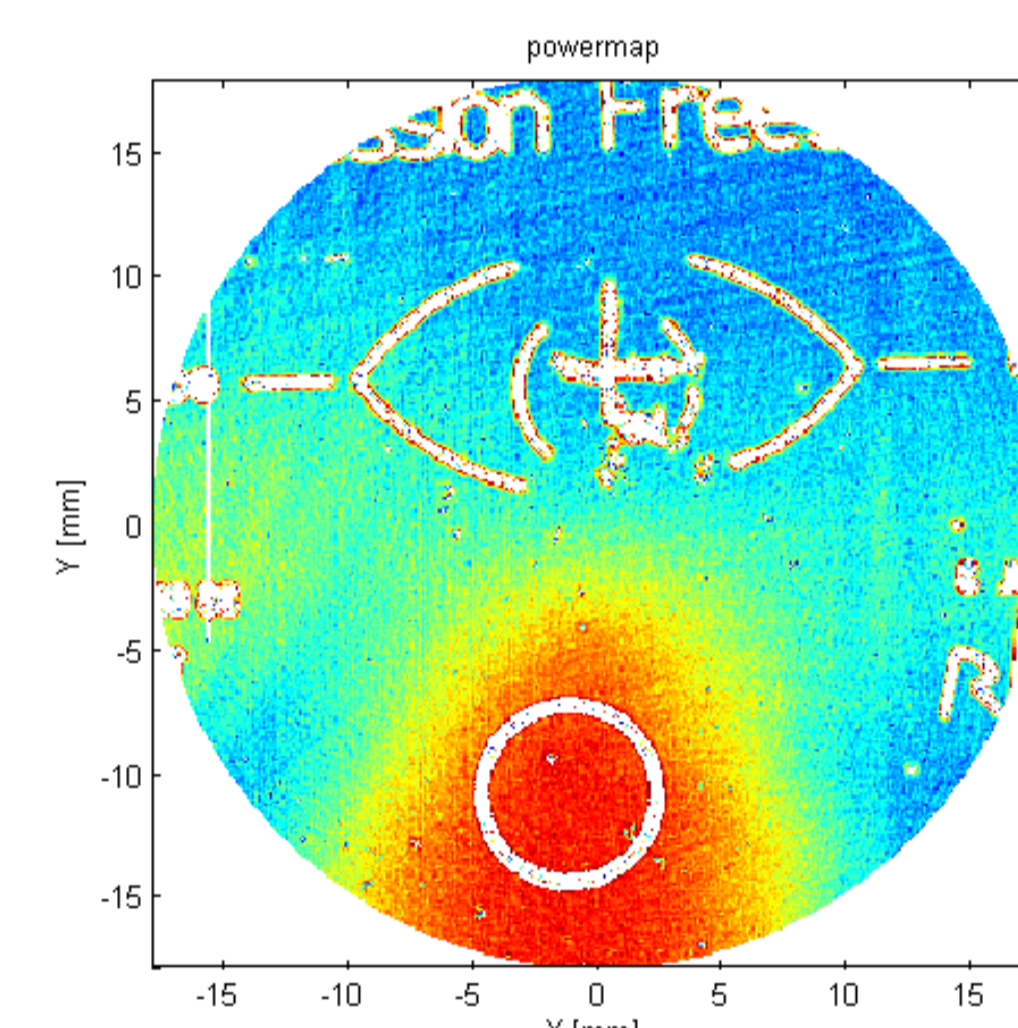


3D-surface:



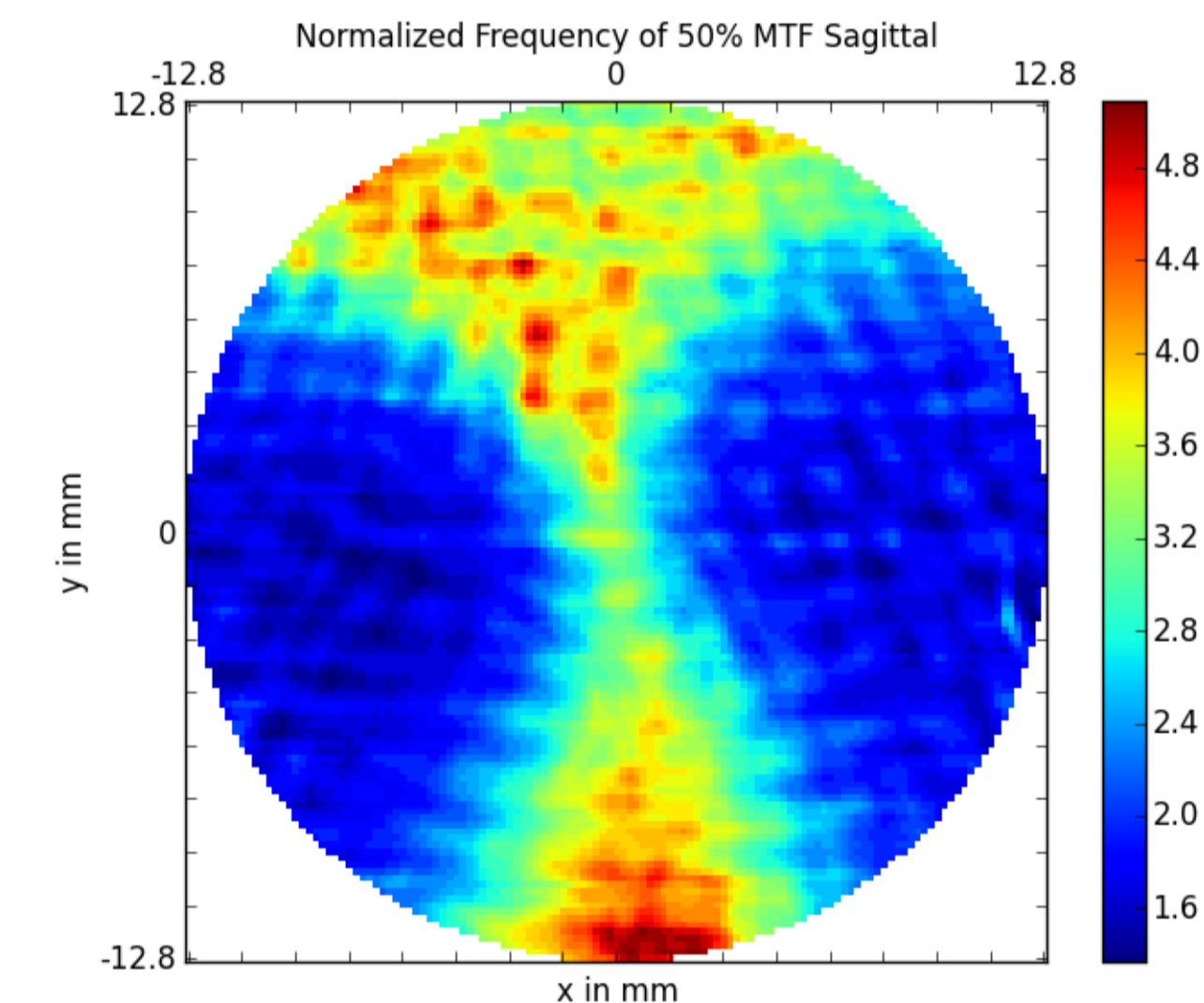
PROGRESSIVE ADDITION LENS (PAL)

POWER MAP = locally dependent optical power $F(x, y) = 1/f(x, y)$:



sample spacing: 0.1 mm, aperture: 36 mm

MTF MAP = locally dependent 50% cut-off frequency $s_{50}(x, y)$:



sample spacing: 0.2 mm, aperture: 25,6 mm

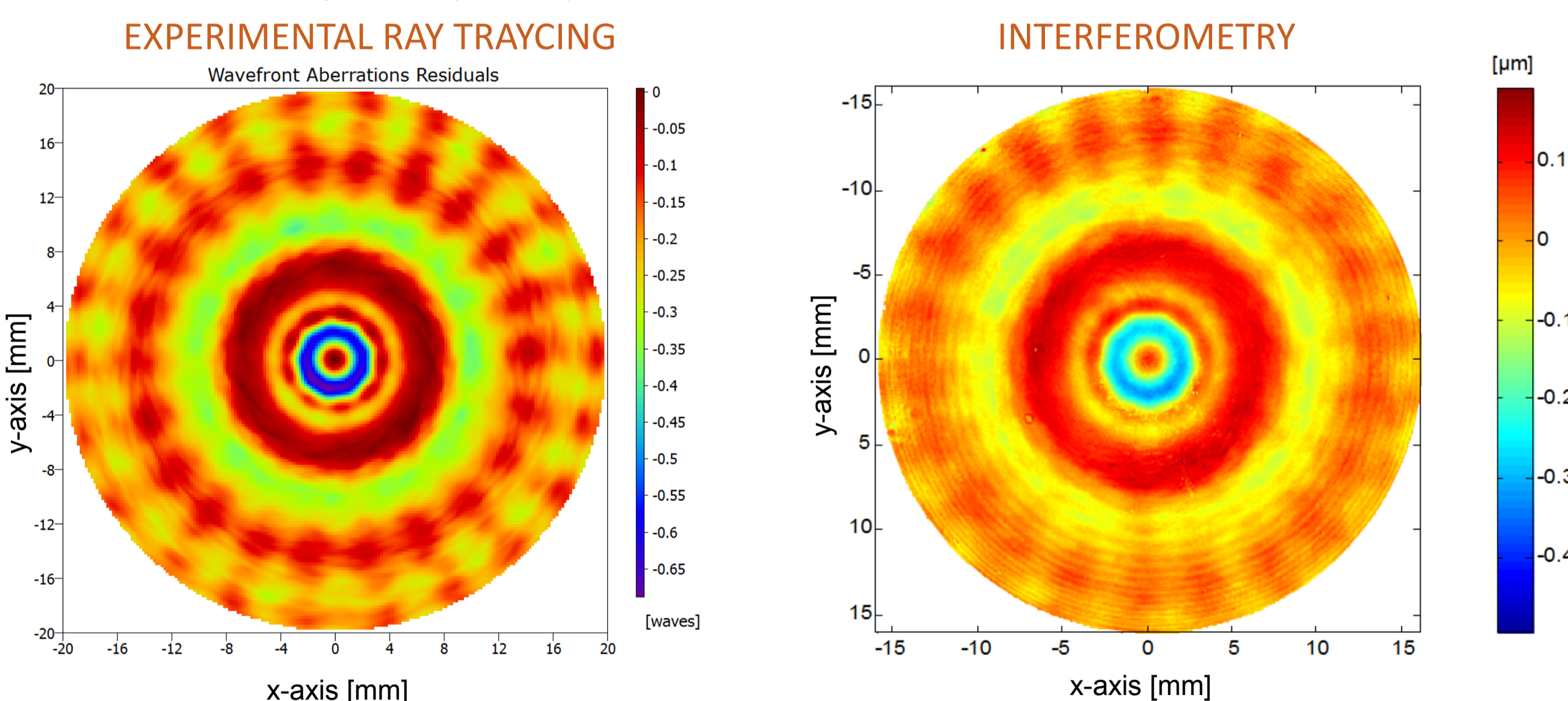
Normalized according to focal length!

WAVEFRONT ABERRATIONS

From ray slopes to gradient of wavefront aberration $W(x, y)$:

$$\vec{\nabla} W(x, y) = \begin{bmatrix} \frac{\partial W(x, y)}{\partial x} \\ \frac{\partial W(x, y)}{\partial y} \end{bmatrix} \approx \begin{pmatrix} T_x \\ T_y \end{pmatrix}$$

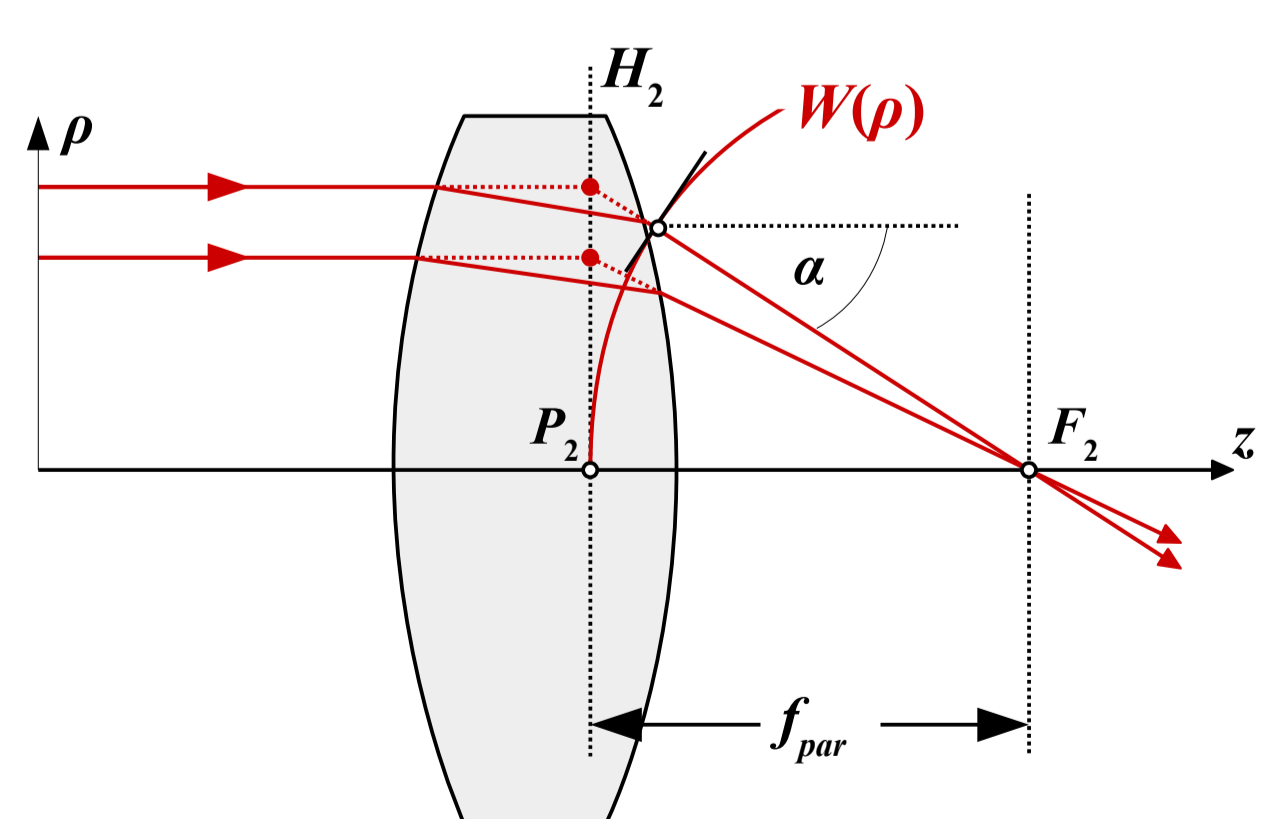
Residual mid- to high-frequency aberrations:



- comparison measurement of precision asphere (F/# 1)
- after subtraction of 28 Zernike terms

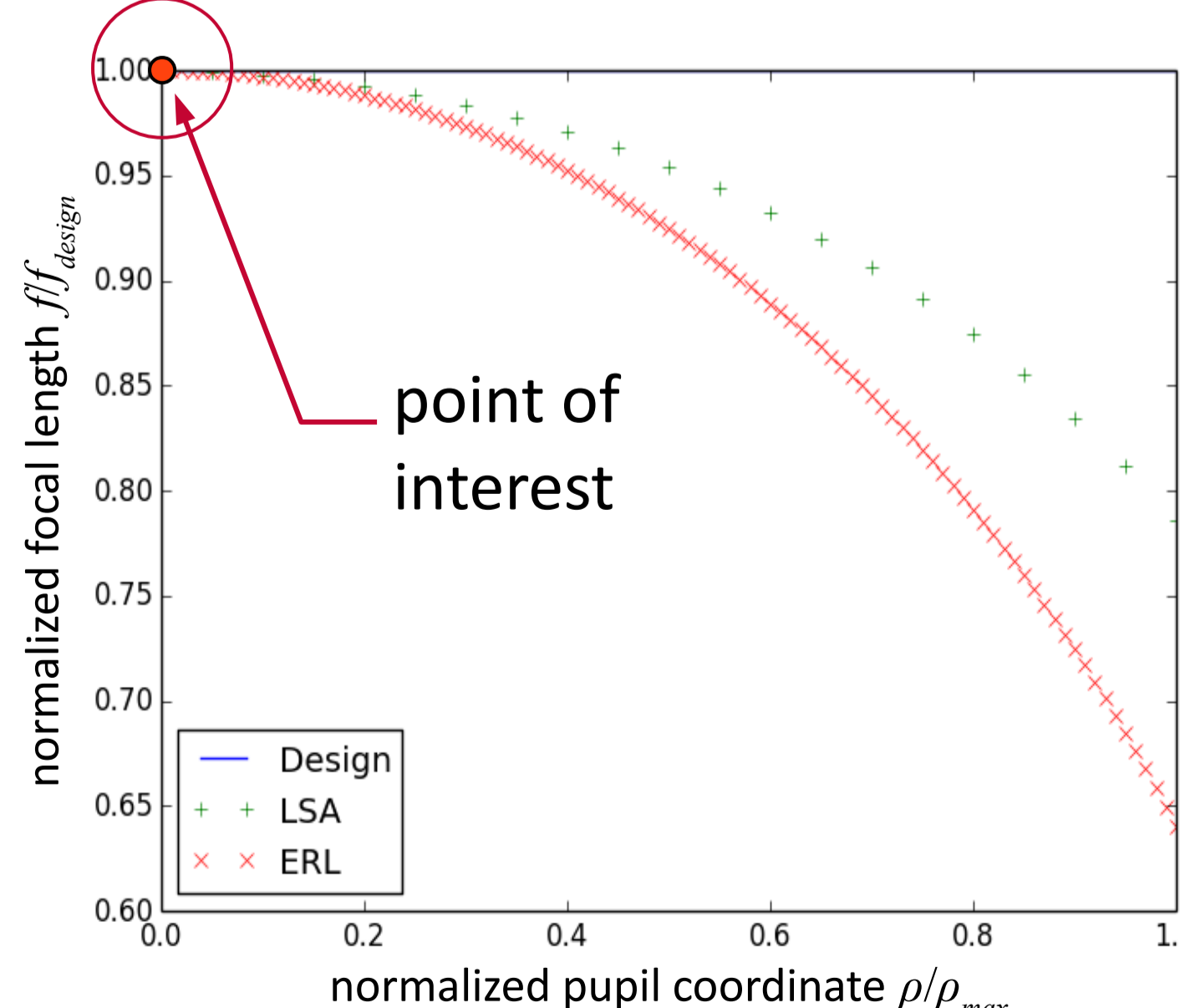
FOCAL LENGTH

Estimate for paraxial focal length from rays slopes



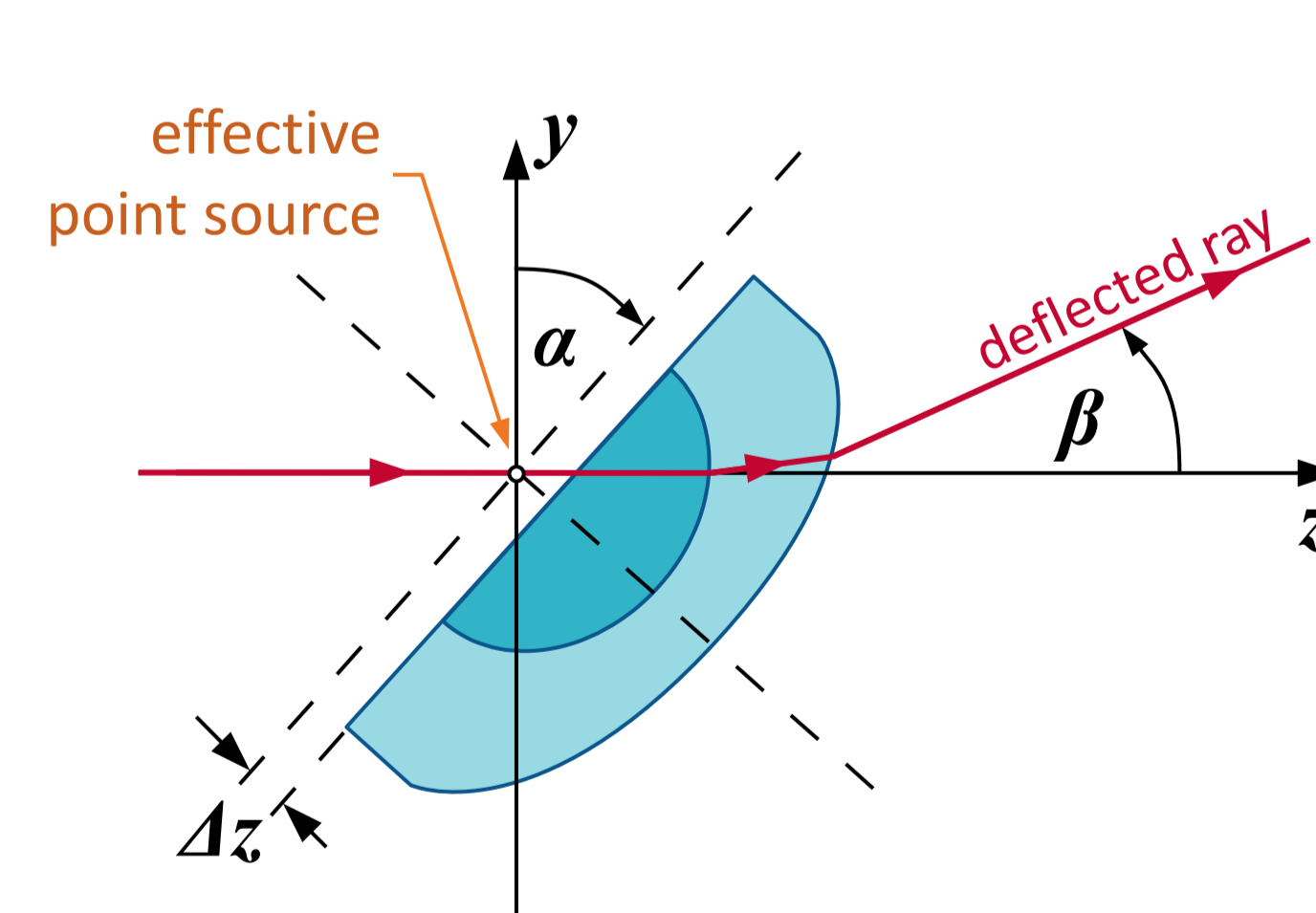
- focal length $f(\rho)$ as function of pupil coordinate ρ from ray slopes
- $f_{par} \approx f(0)$ from interpolation

influence from aberrations:

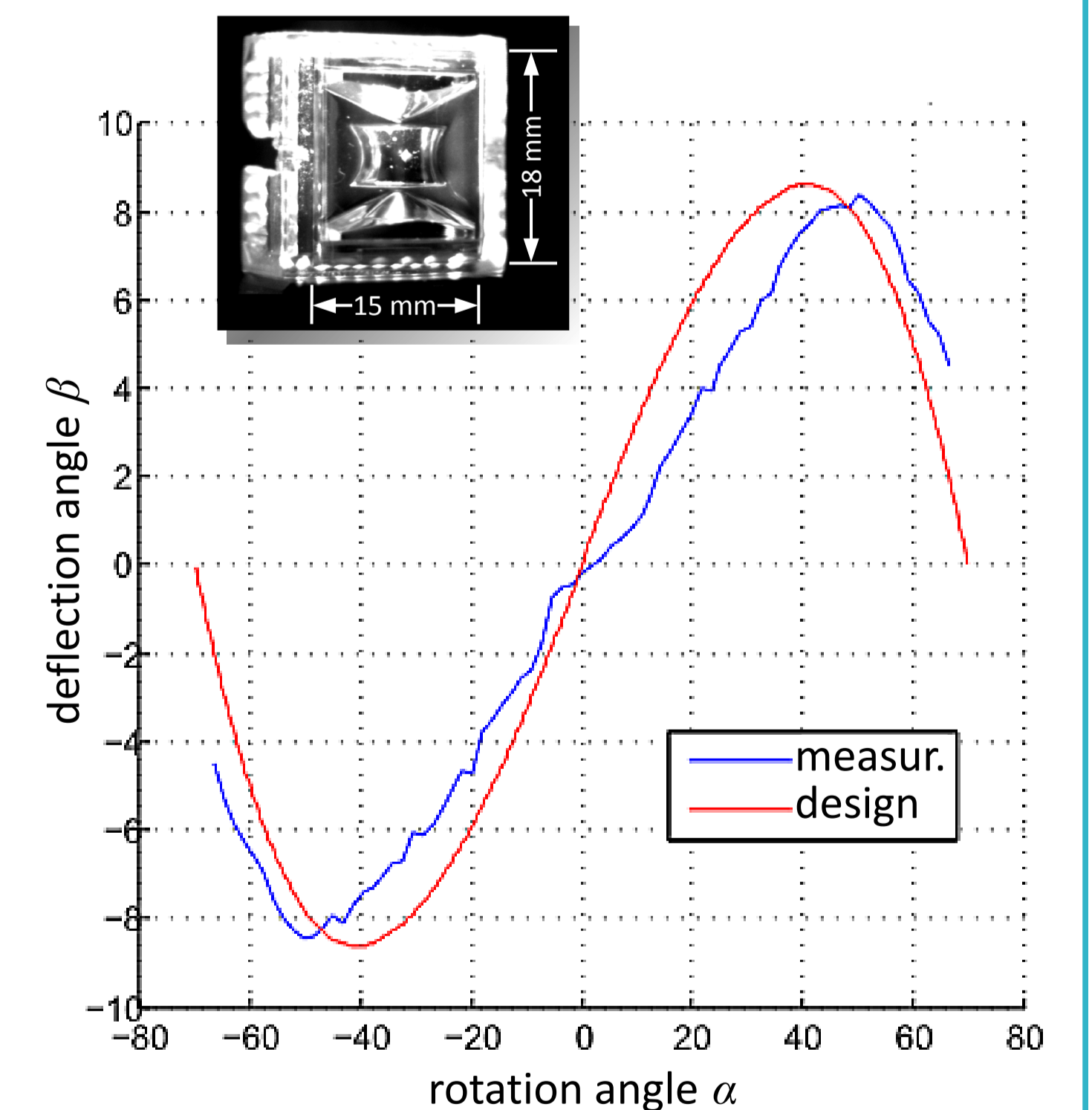


LED SECONDARY FREEFORM OPTICS

For special applications: signal lighting, hazard beacons



- rotation around α
- measuring $\beta = f(\alpha)$
- calculating expected intensity distribution $I(\alpha)$



CONCLUSION

Experimental ray tracing proved to be a flexible and diverse measurement principle usable for characterization of single lenses, lens systems, aspheres and freeforms with respect to shape and optical performance. It allows for the determination of parameters beyond the scope of what can be achieved with available techniques today.

in cooperation with:



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