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FAKULTÄT FÜR PHYSIK

METEOROLOGIE

MIM

Simulation of the effect of the laser beam profile on the overlap function of lidar systems

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Our focus

- Gaussian beams**:** common assumption when simulating the **overlap** function of a lidar system
- Which **errors** are expected when the lase beam profile is assumed to be:
  - **Gaussian** (00 TEM – best fitted circle)
  - **Elliptical** (Best fitted ellipse – D4σ method)

How we did it

- **Ray-tracing** is used to simulate the overlap function/telecover test
- **"Real beams"**: Multi-modal beams (mixing up to 3rd order TEMs)
- The beam waist is adjusted to scale all laser beam profiles to the **same beam divergence**
- Comparison of the overlap function/telecover test among the "real" and "assumed" beams

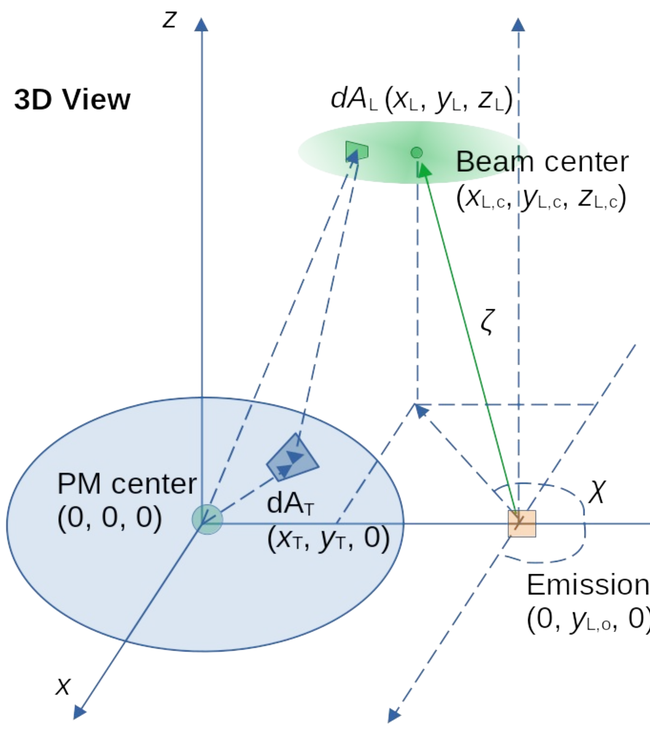
What did we find?

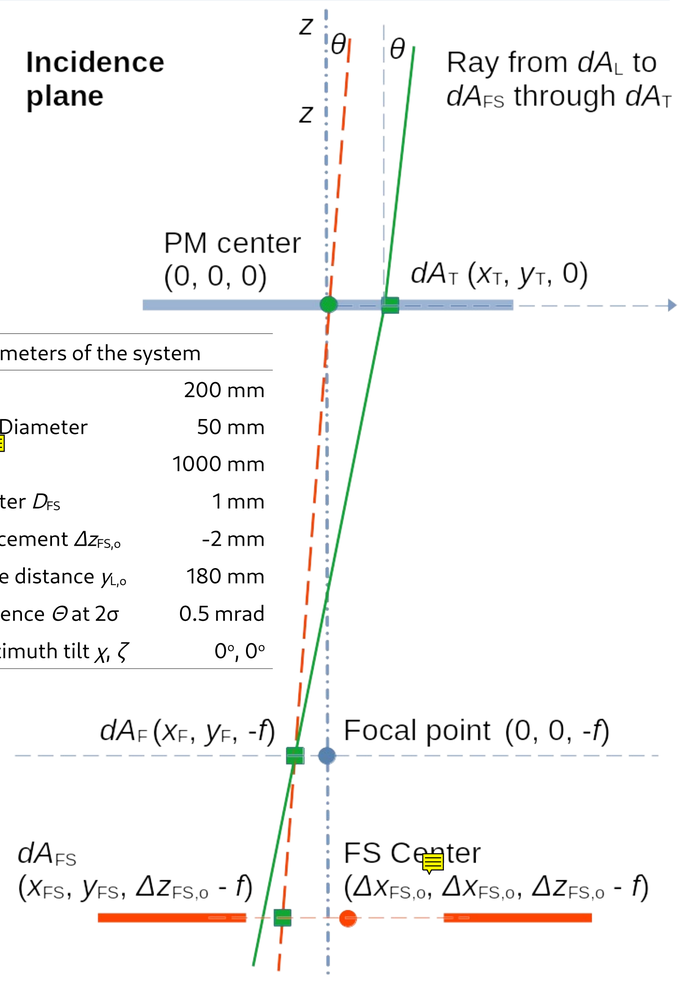
- Rel. **errors up to ~20%/7%** of the overlap function at $O(z) \geq 0.3$ are expected if a **Gaussian/elliptical** beam profile is assumed
- **Beam profile**: Accurate overlap calculations cannot be achieved without a priori knowledge of the laser beam profile
- **Telecover test**: distance of full overlap at ±5% sector deviation might not correspond to $O(z) = 0.95$

Ray-tracing geometry

$$x_L = x_{L,w} + x_{L,c} \qquad y_{L,c} = y_{L,o} + z_{L,c} \tan\zeta \sin\chi$$

$$y_L = y_{L,w} + y_{L,c} \qquad x_{L,c} = z_{L,c} \tan\zeta \cos\chi$$





Ray-tracing parameters of the system	
PM Diameter D_T	200 mm
SM Obscuration Diameter	50 mm
Focal length f	1000 mm
Field stop diameter D_{FS}	1 mm
Field stop displacement $\Delta z_{FS,o}$	-2 mm
Laser – Telescope distance $y_{L,o}$	180 mm
Full beam divergence Θ at 2σ	0.5 mrad
Laser zenith & azimuth tilt χ, ζ	0°, 0°

Related Equations & Assumptions

$$x_{FS} = \frac{x_T - x_L}{z_L}(f - \Delta z_{FS,o}) + x_T \frac{\Delta z_{FS,o}}{f}$$

$$y_{FS} = \frac{y_T - y_L}{z_L}(f - \Delta z_{FS,o}) + y_T \frac{\Delta z_{FS,o}}{f}$$

$$(x_{FS} - \Delta x_{FS,o})^2 + (y_{FS} - \Delta y_{FS,o})^2 \leq \left(\frac{D_{FS}}{2}\right)^2$$

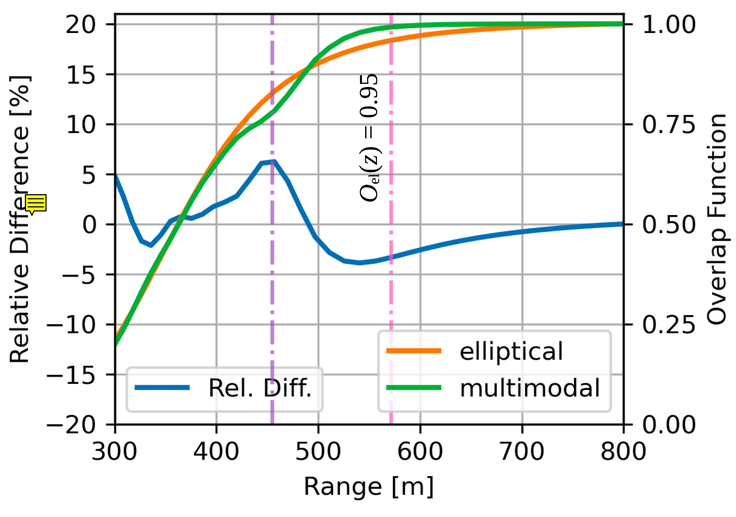
$$O(z) = \iint_{A_L} \iint_{A_T} \frac{\eta T_O f_{FS} f_T B_{air} E_L \, dA_T \, dA_L}{z^2}$$

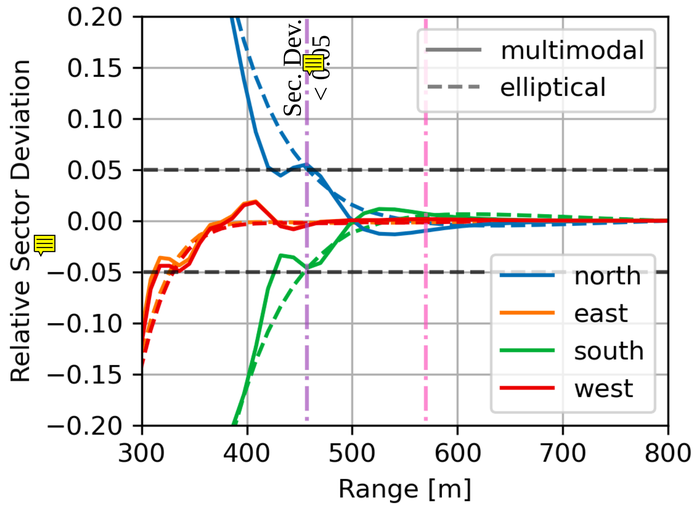
- PM/SM: Primary/Secondary mirror
- FS: Field stop
- Coordinates of the laser beam part dA_L
  - x_L, y_L, z_L in the PM ref. system
  - $x_{L,w}$, $y_{L,w}$ in the beam center ref. system
- $x_{L,c}$, $y_{L,c}$: coord. of the beam center
- x_T, y_T: coord. of the PM surface part dA_T
- x_{FS}, y_{FS}: coord. of the FS surface part dA_T
- $\Delta x_{FS,o}$, $\Delta y_{FS,o}$, $\Delta z_{FS,o}$: field stop displacement
- D_{FS}: field stop diameter
- $y_{L,o}$: y coordinate of the laser
- f: telescope focal length
- f_{FS} (x_T, y_T, z_T): obscuration of the FS
- f_T (x_T, y_T, z_T): obscuration of the PM
- T_o: transmission of the receiver optics
- $E_L(x_L, y_L, z_L)$: average pulse irradiance
- B_{air} (x_L, y_L, z_L): attenuated backscatter
- O(z): Overlap function
- ζ, χ: Zenith and azimuth tilt of the laser

Assumptions:

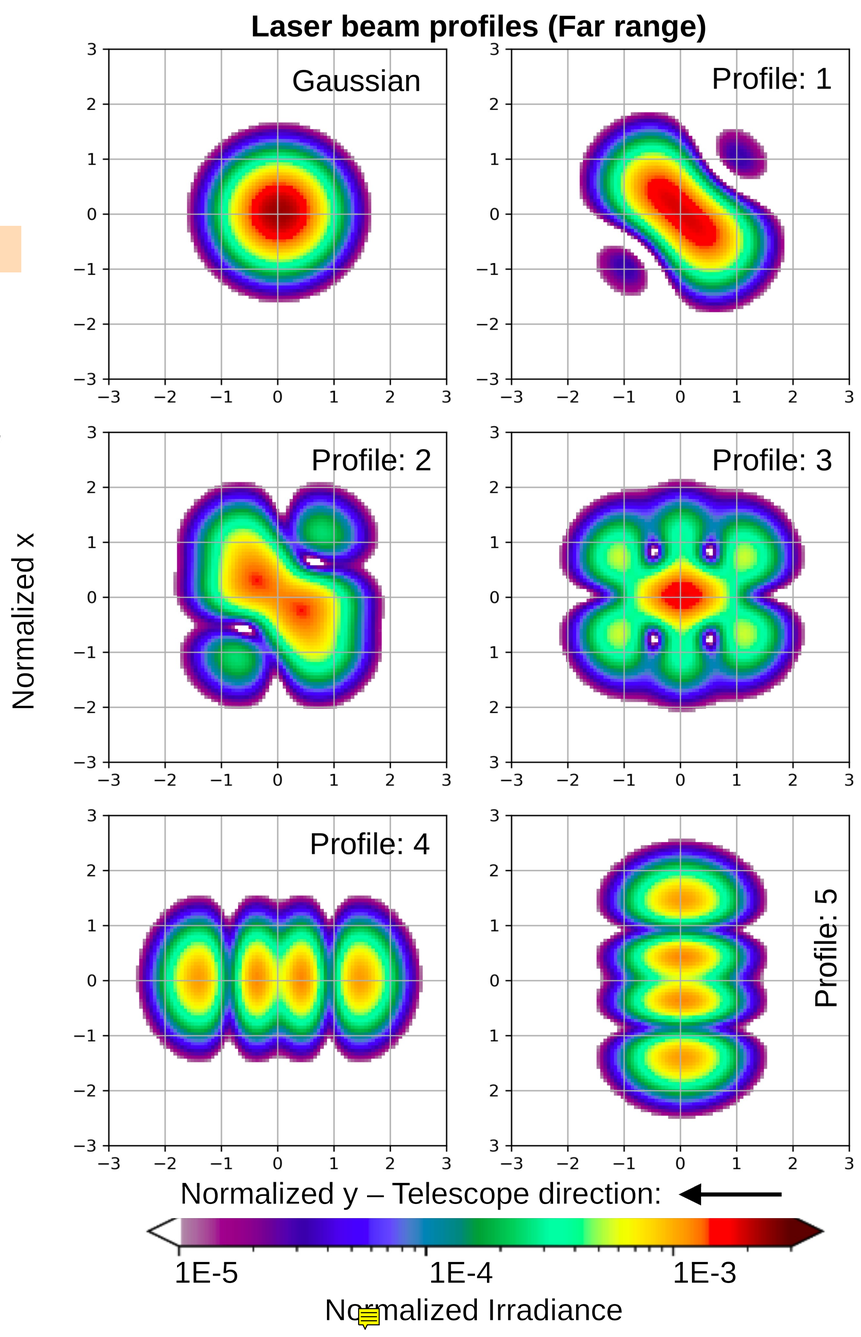
- **telescope** aberrations are negligible
- the **FS** is the limiting aperture
- negligible spatial inhomogeneities of the **detector's gain**
- negligible spatial inhomogeneities of the **receiving optics transmission**
- negligible angle of incidence effects on the **interference filters**

Overlap function & Telecover test of Profile 4: Elliptical vs Multi-modal

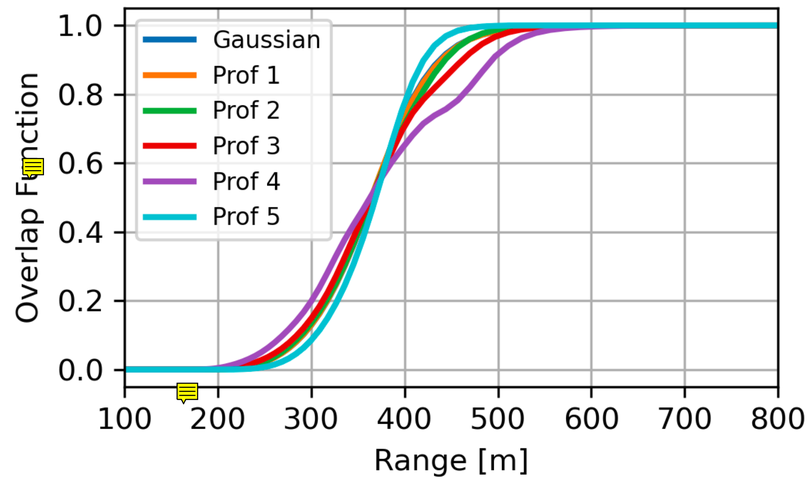




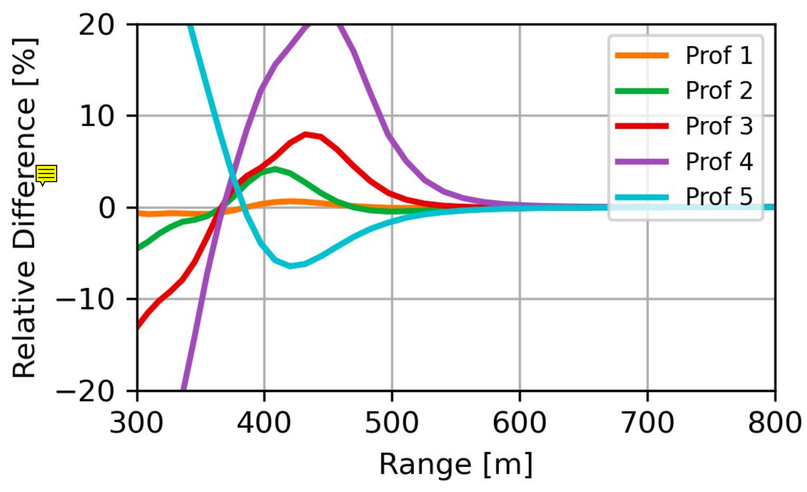
Simulated multi-modal beam profiles (far range)



Simulated overlap function per beam profile



Relative differences of the overlap function Gaussian vs Multi-modal



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References

[1] O. A. Schmidt *et al.*, "Real-time determination of laser beam quality by modal decomposition," *Opt. Express*, vol. 19, no. 7, pp. 6741–6748, Mar. 2011, doi: 10.1364/OE.19.006741.
[2] O. Svelto, *Principles of Lasers*. Boston, MA: Springer US, 2010. doi: 10.1007/978-1-4419-1302-9.