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Applied Physics
Friedrich-Schiller-Universität Jena

Metrology and Sensing

Lecture 11-3: Phase retrieval

2021-01-14

Herbert Gross

Content

- Apodization
- Image processing
- Examples

Phase Retrieval with Apodization

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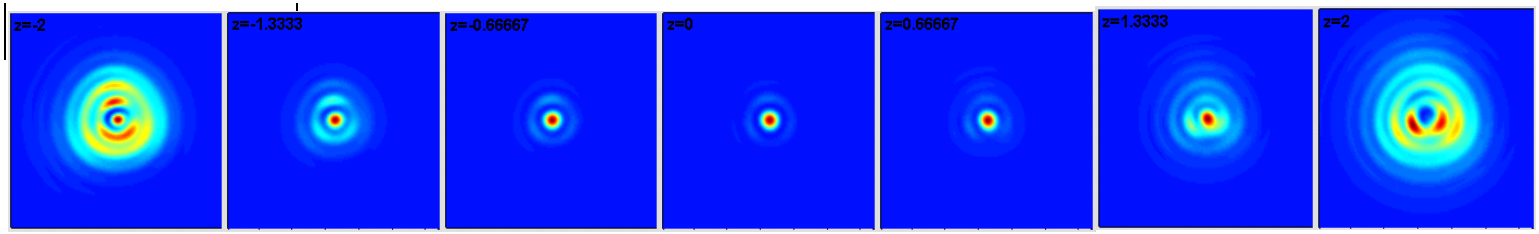
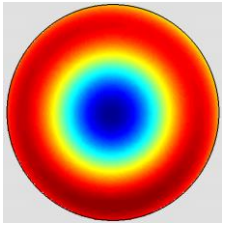
- Analysis taking apodization into account greatly improves the result

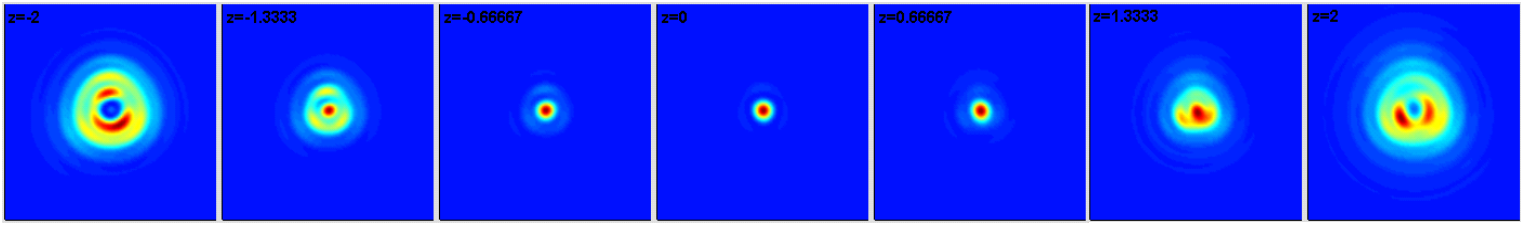
input-stack



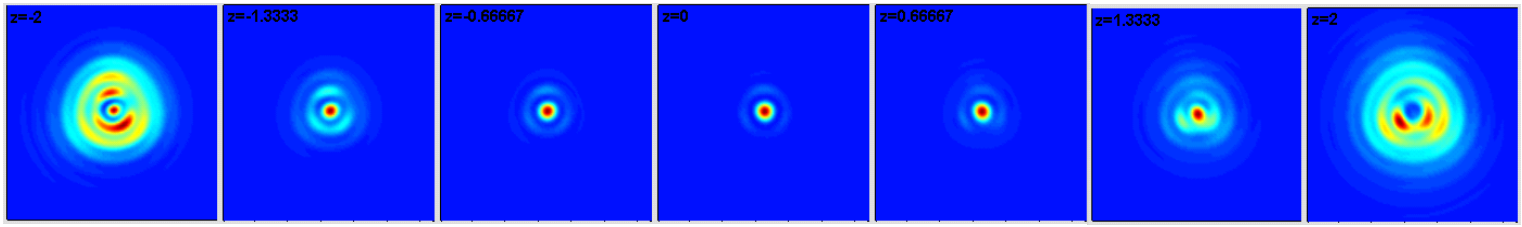


apodization

analysis without apodization



analysis with apodization



Phase Retrieval with Apodization

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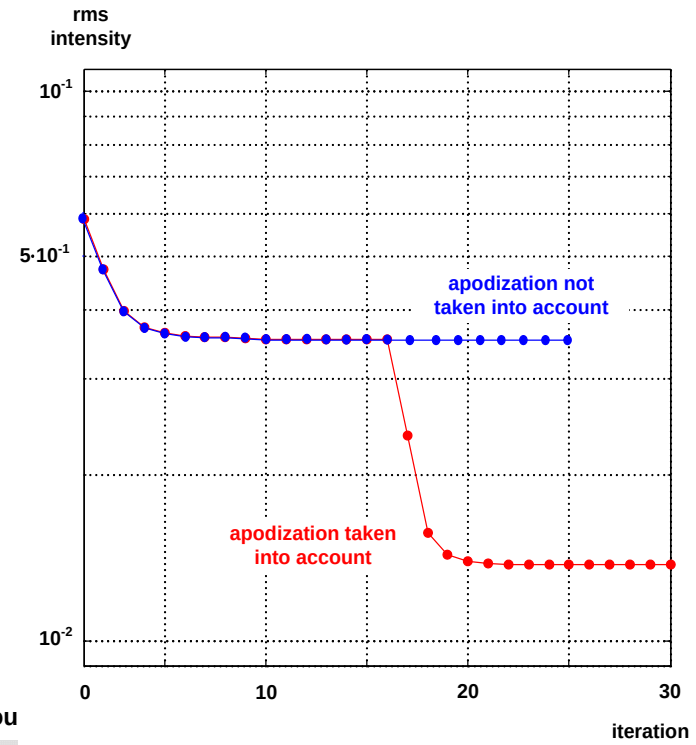
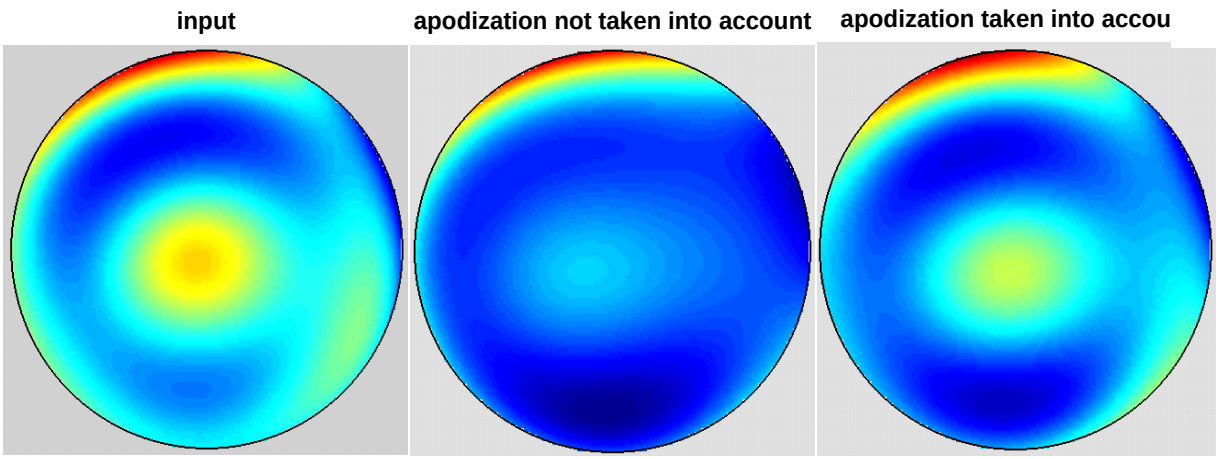
- If the pupil shows a significant illumination distribution:

  apodization must be taken into account
- Apodization can be fitted too
- Better: measured apodization used





Phase Retrieval with Apodization

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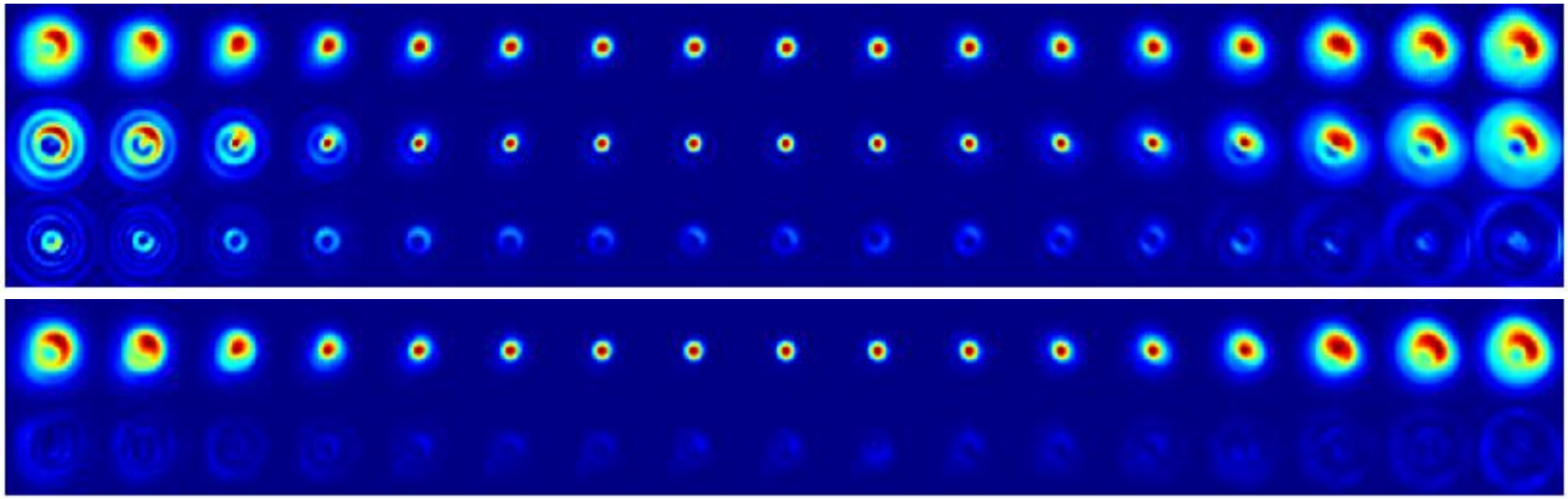
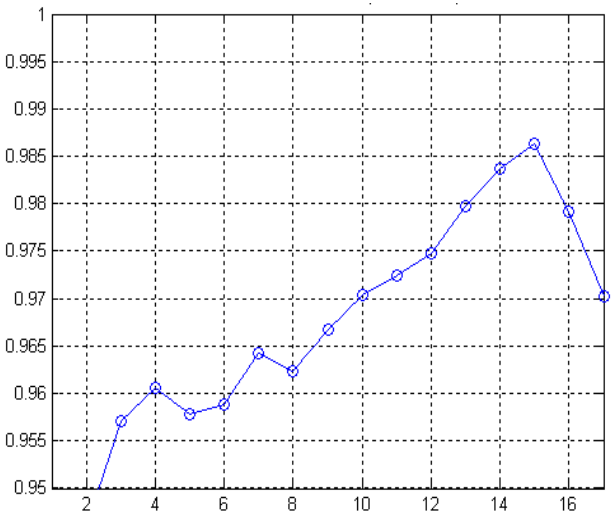


- Retrieval without / with Apodization
- Correlation over z



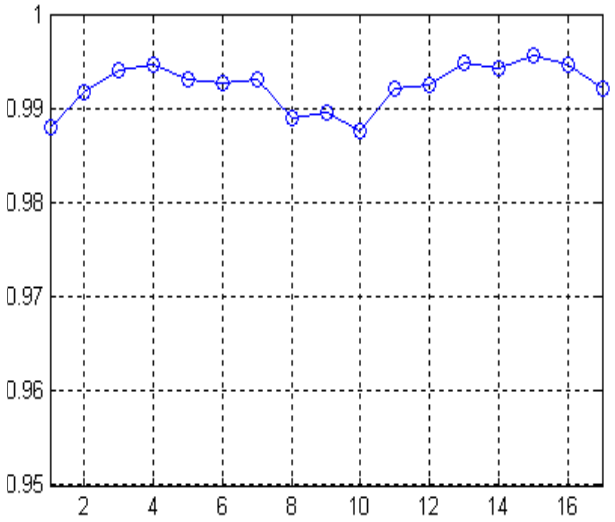
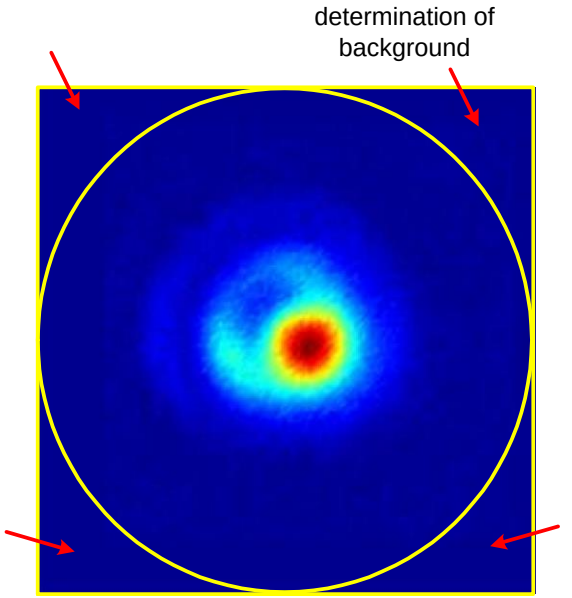
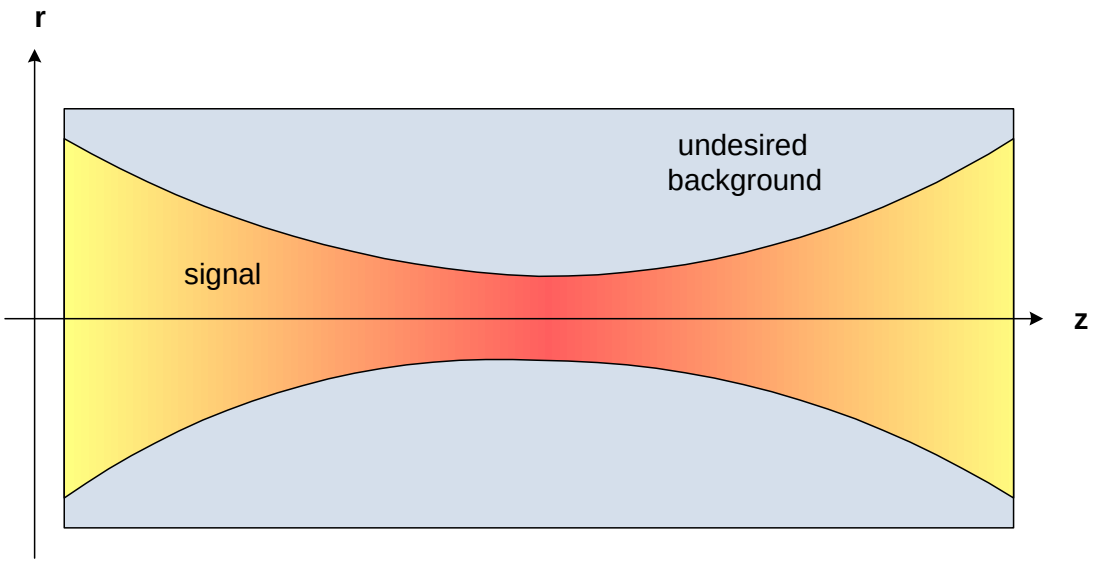
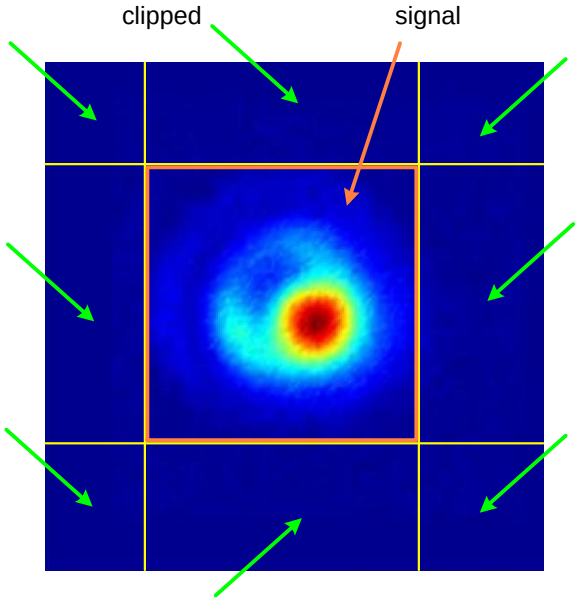


Image Processing

- Determination background intensity preferred: corner,every z-plane individually
- Truncation of outer region without signal
- Subtraction of underground







Noise in Signal

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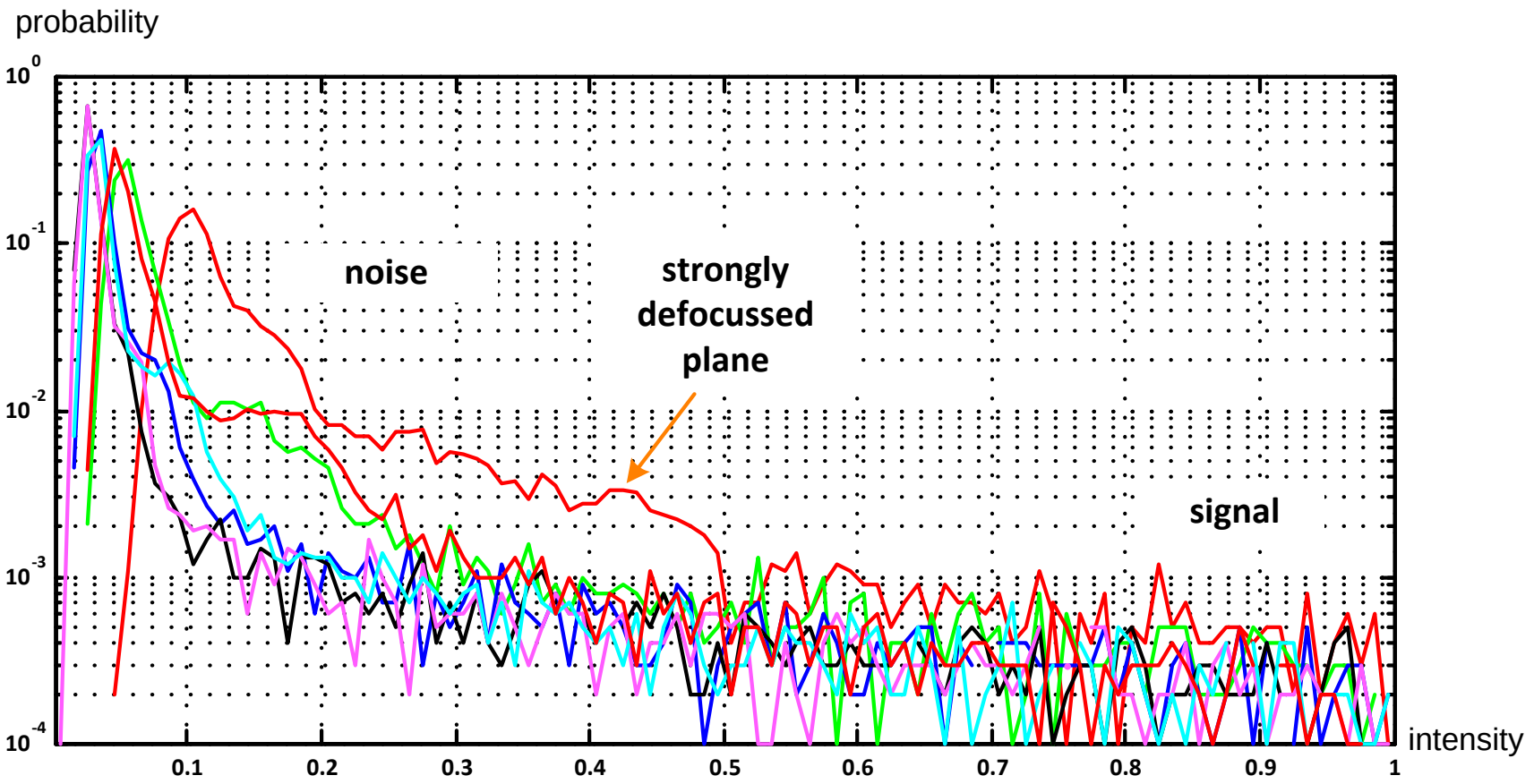
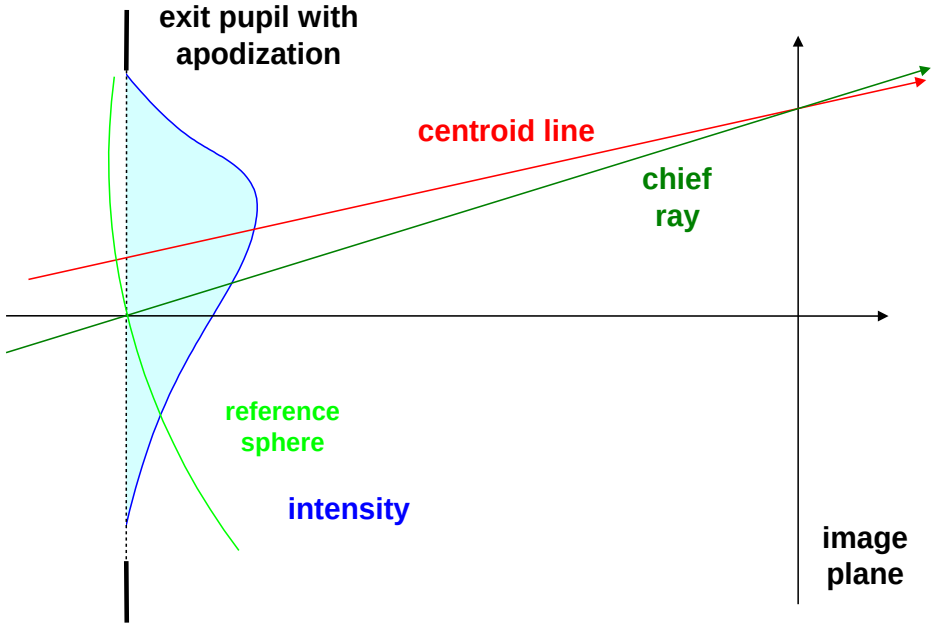
- Noise depends on light level
- Defocussed z-planes more critical
- Modal fit with Zernikes is low pass filter

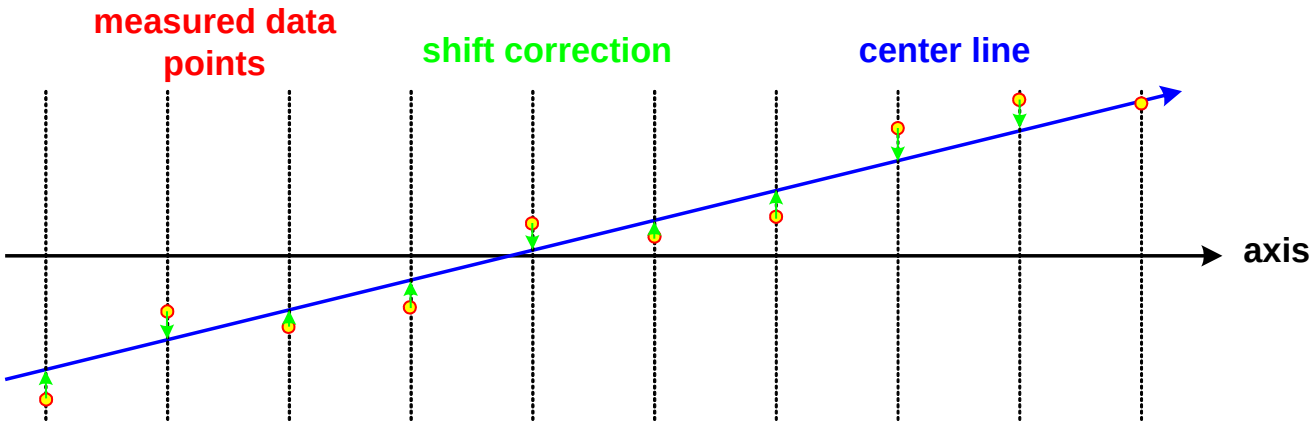


Centering - Line of Sight

Centering of z-stack images :

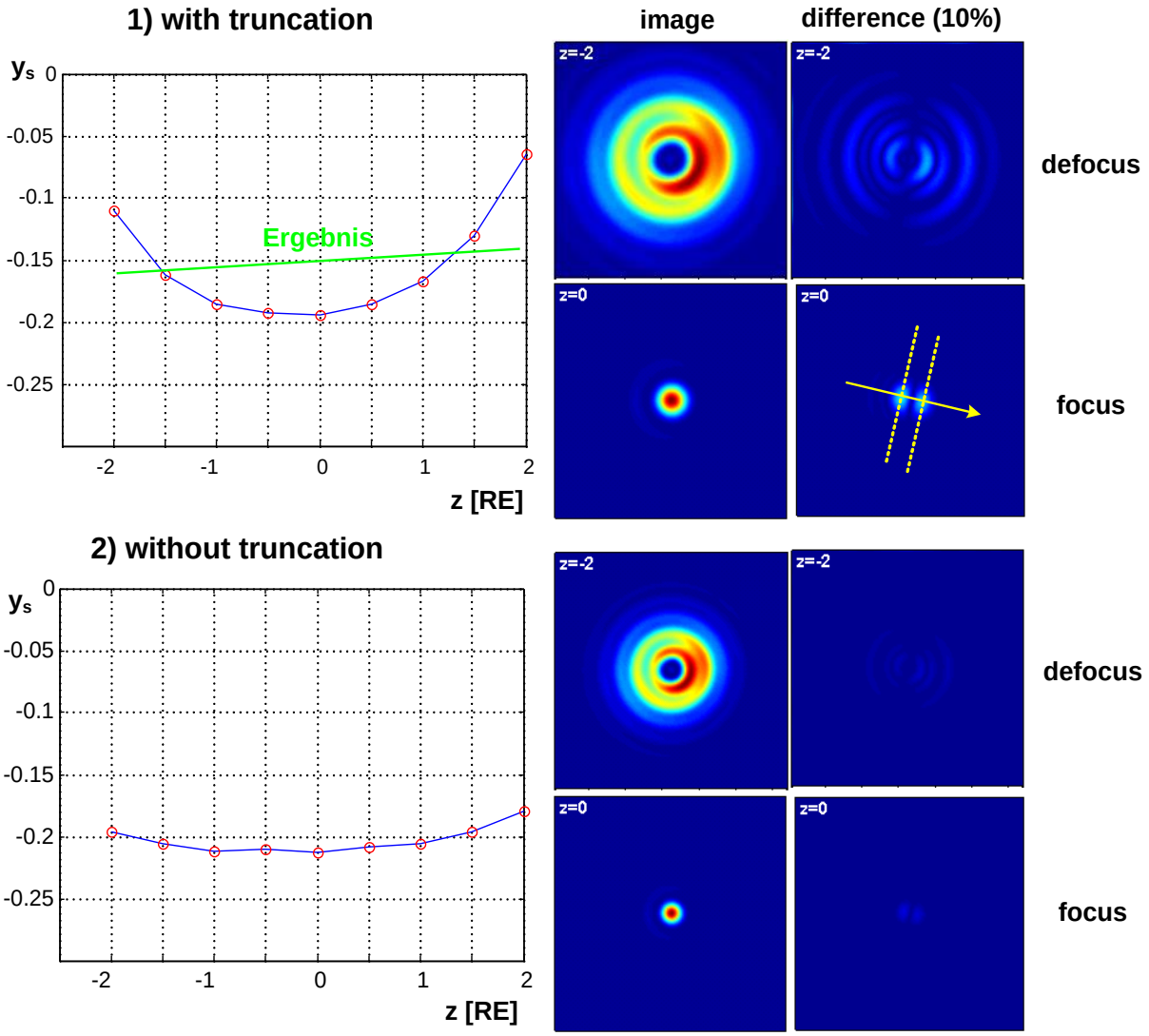
1. Line of sight
   (centroid moves exactly on a line))
2. Systematic errors due to mechanical
   inaccuracy (line tilt)
3. Statistical errors





Truncated Beam Profile

- Problems for truncation of the beam profiles: errors in cetroid deter-mination



Object Space Defocussing

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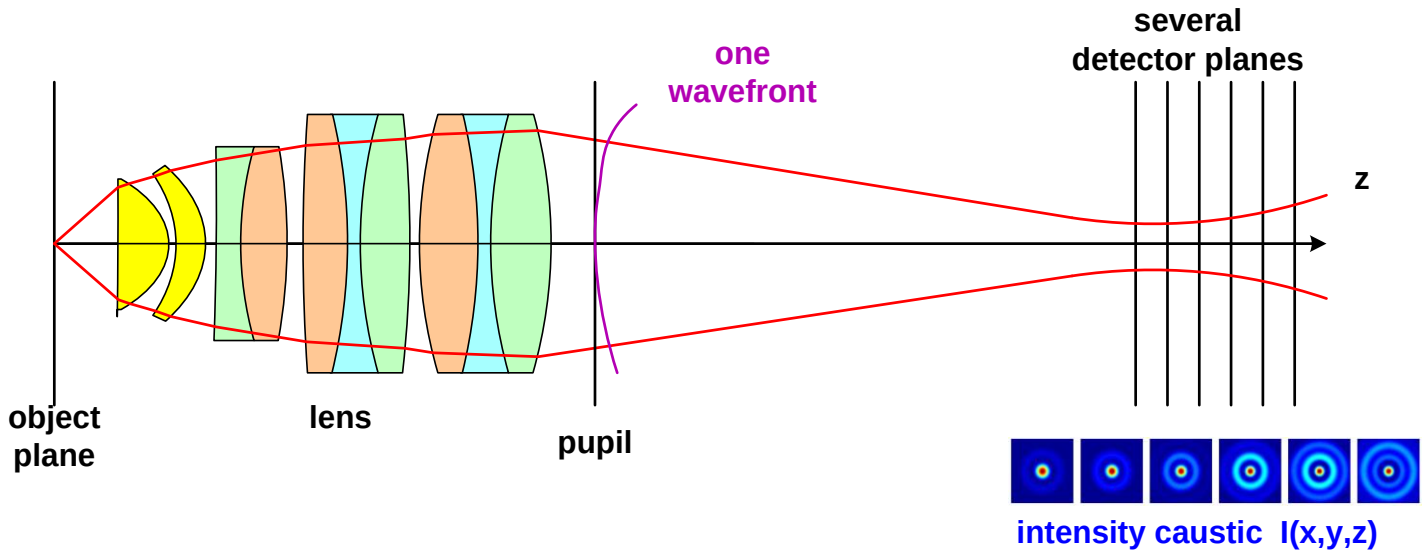
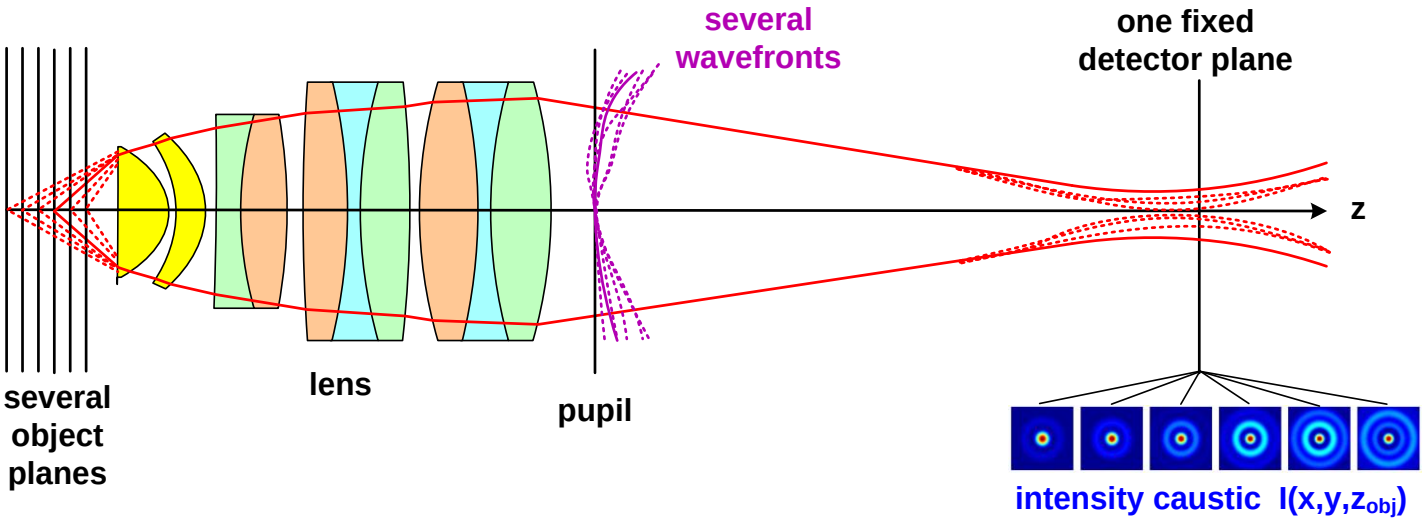
a) defocussing in image space



b) defocussing in object space



Object Space Defocussing

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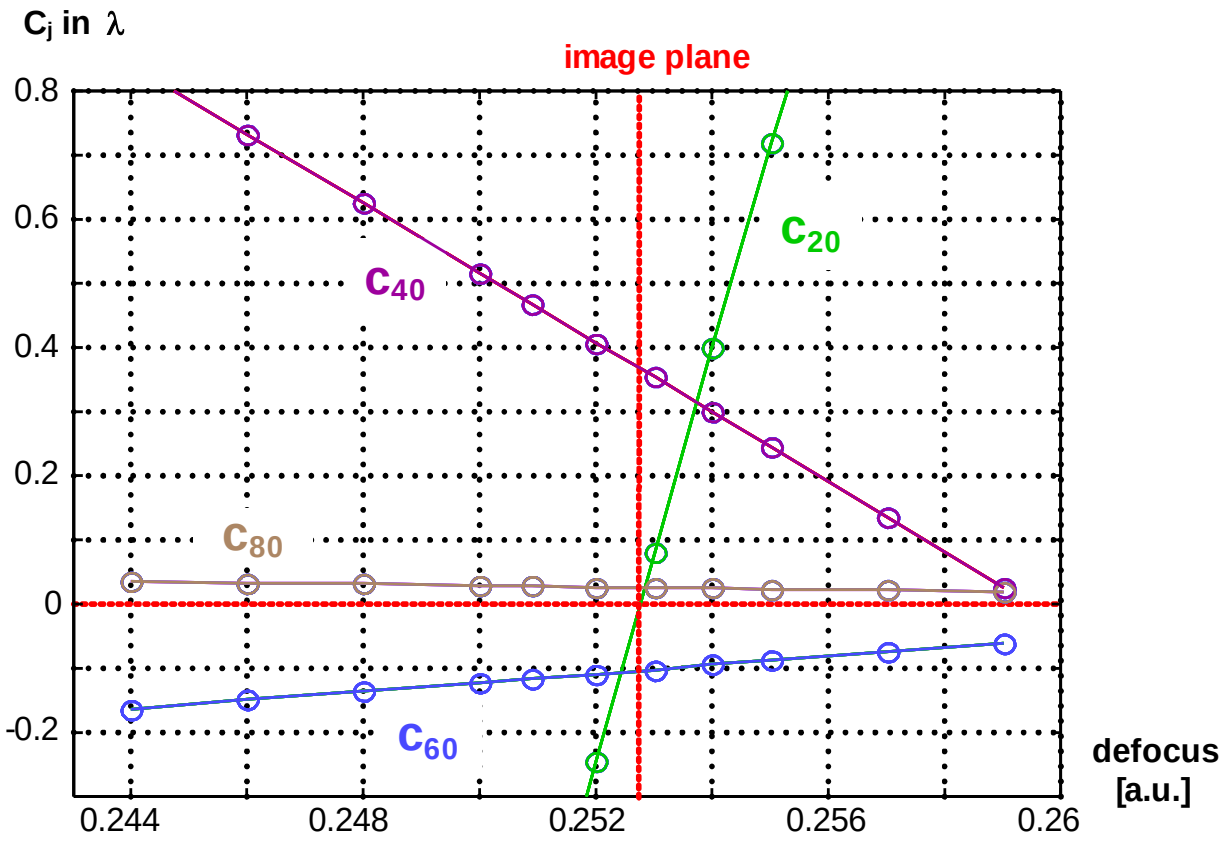
- Good Linearity of Zernike coefficients
- Small retrace non-linearity

$$c_j(z) = c_{jo} \cdot \left(1 + + \Delta c_{lin} \cdot \frac{\Delta z}{R_E}\right)$$



Phase Retrieval Accuracy

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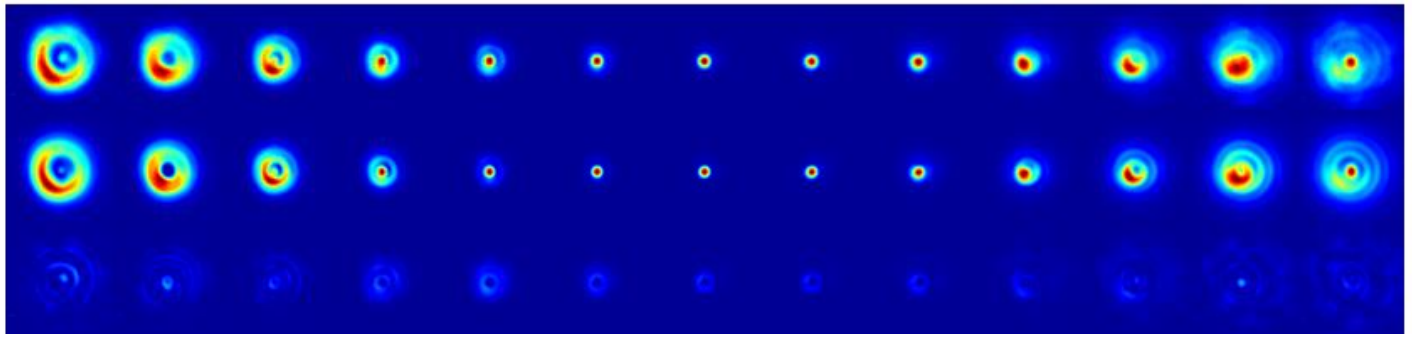
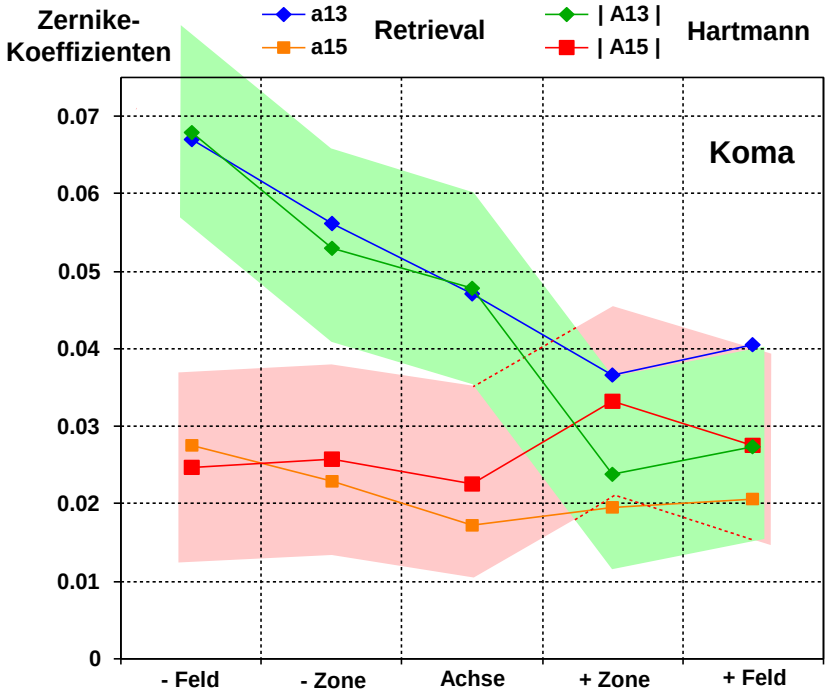
Evaluation of real measuring data



Comparison of Zernike coefficients with Hartmann test results: accuracy in the range λ/100



Separation of Circular Symmetric Effects

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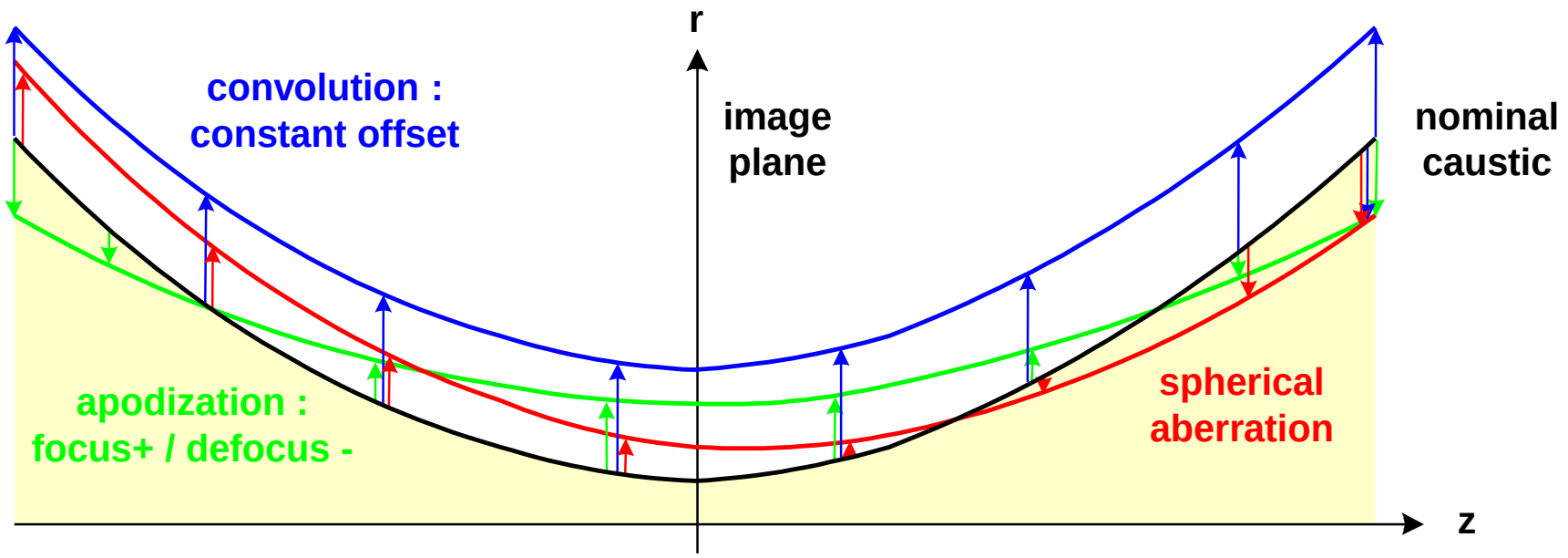
- Circular symmetric contributions can be separated over defocussing range:
  1. apodization: increase in diameter in focal region
  2. finite pinhole size: uniform broadening vs defocus
  3. spherical aberration: asymmetric around focal plane



Phase Retrieval Reproducability

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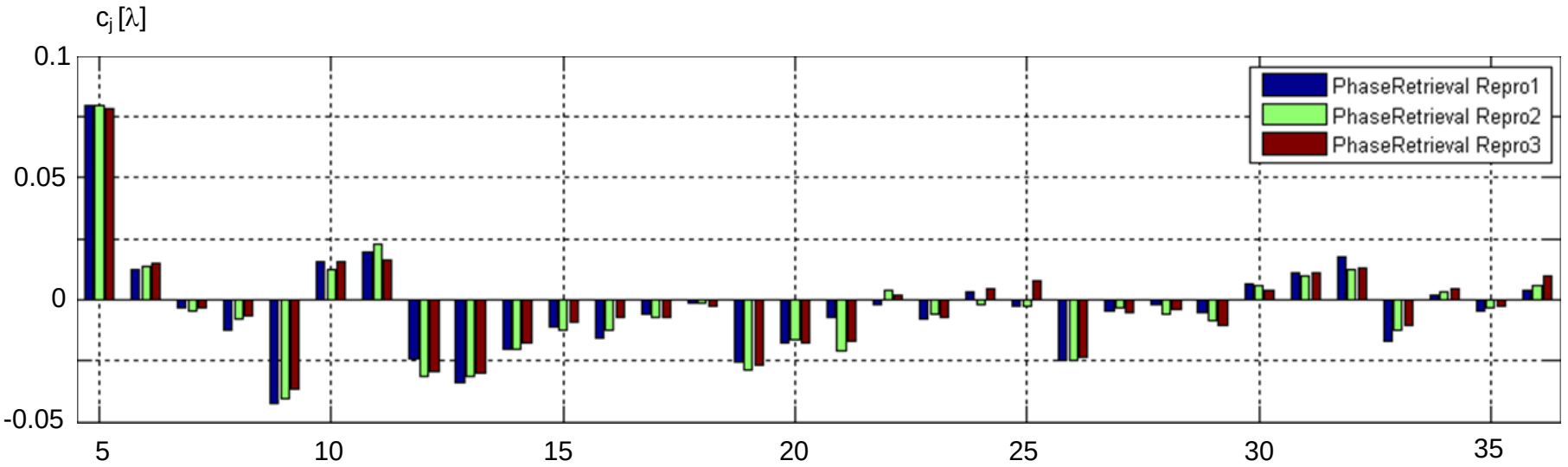
- Reproducability of 3 measurements
- Very good agreement with uncertainties in the range of λ/100 for every Zernike coefficients for the first 36 terms
- No dependence on symmetry



Example Residuum

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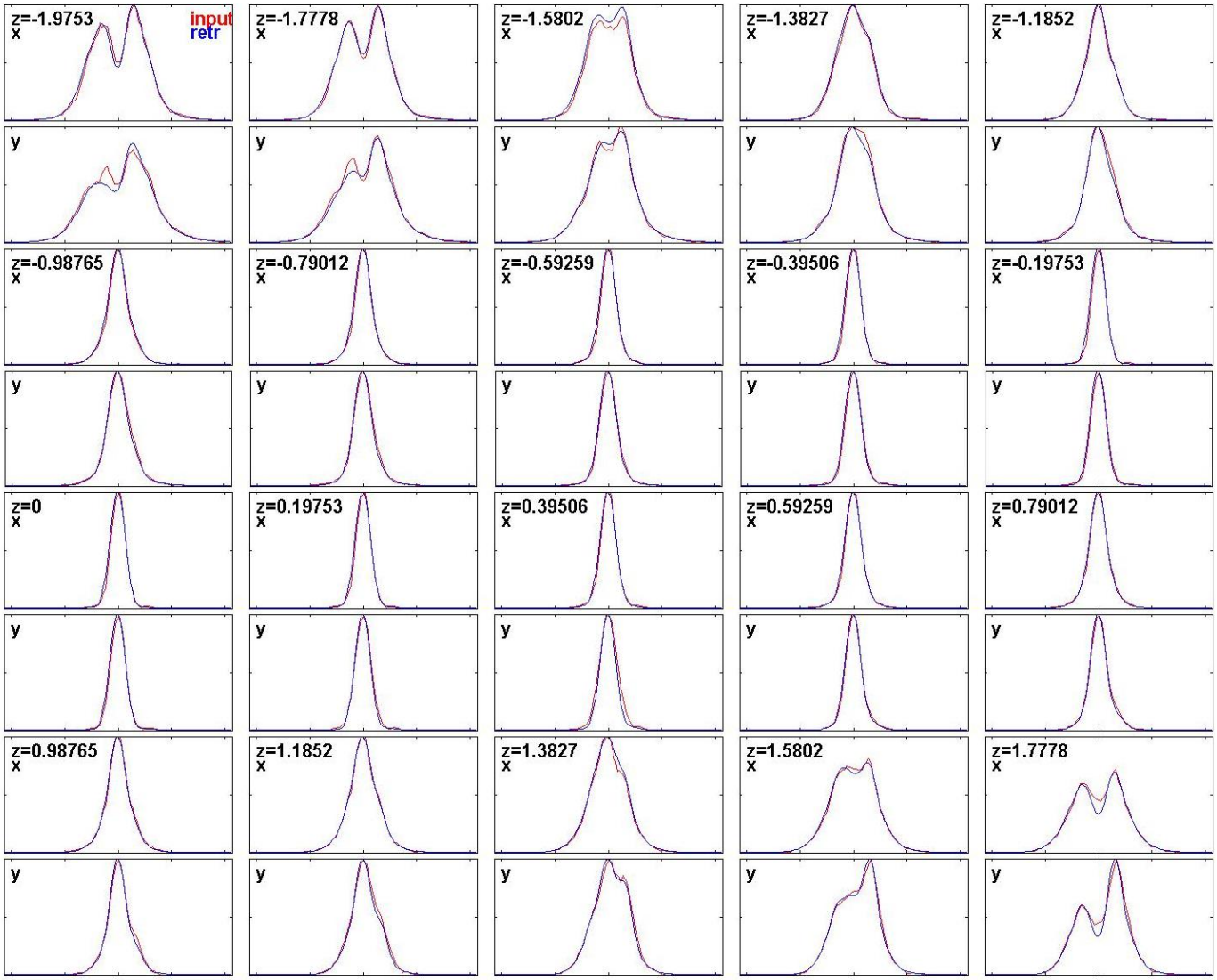
- Comparison of intensity profile cross sections x / y
- Blue : Input
  Red : Model



Problems and Suggestions

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- Data not truncated
- Centering of stack images on common line
- Don‘t use more than 36 Zernikes
- Pinhole not larger than 2x D_{airy}
- Deconvolution for nearly incoherent illumination
- Preferred dynamic pinhole-match and forward convolution of finite size
- Proposed: n > 7 z-planes in the intervall -2 Ru...+2 Ru
- At least 6 detector pixels inside the Airy diameter in the focus plane
- Denoising of data
- Subtraction of background
- Low-pass filtering of Zernike modal functions in pupil
- If pupil apodization present: must be taken into account
- Normalization of intensity in every z-plane