Characterization of the transverse profile of the photocathode laser

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Characterization of the transverse profile of the PITZ photocathode laser
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HELMHOLTZ
ASSOCIATION

DESY

Contents

Introduction

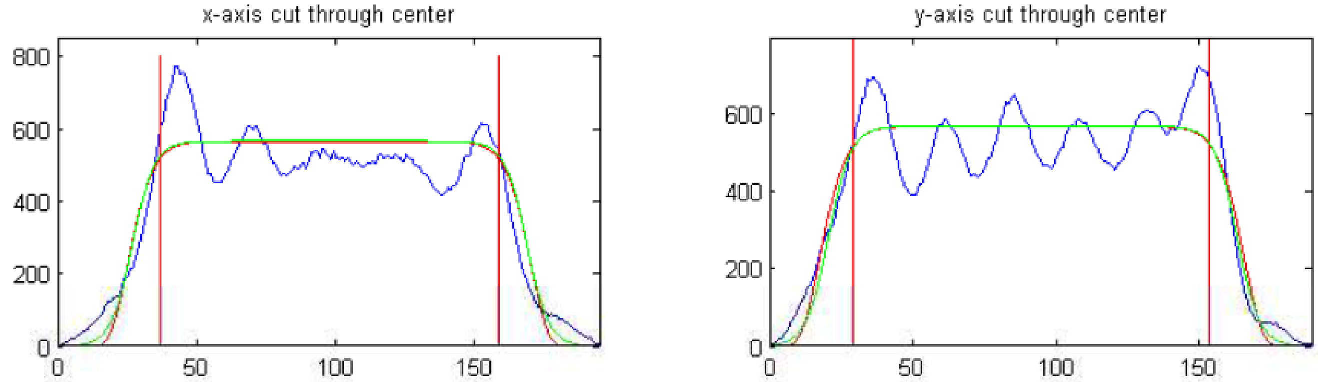
- Previous studies suggest flat-top transverse laser profile for best emittance
- Further studies: modulations on flat-top have negative influence on emittance
- Up to now only 2 parameters for laser characterization: intensity & BSA size
- New parameters have to be found to in order to characterize inhomogeneities and investigate their influence on beam emittance

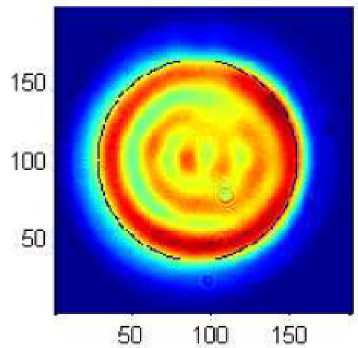
Area of interest

- Reason for AoI: limit homogeneity analysis to flat-top part, exclude flanks
- AoI finding must be automated for reproducible results
- First 1D approach with projections on x- and y axis failed (too inaccurate)
- New approach: 2D-fitting

Area of interest – 2D fit

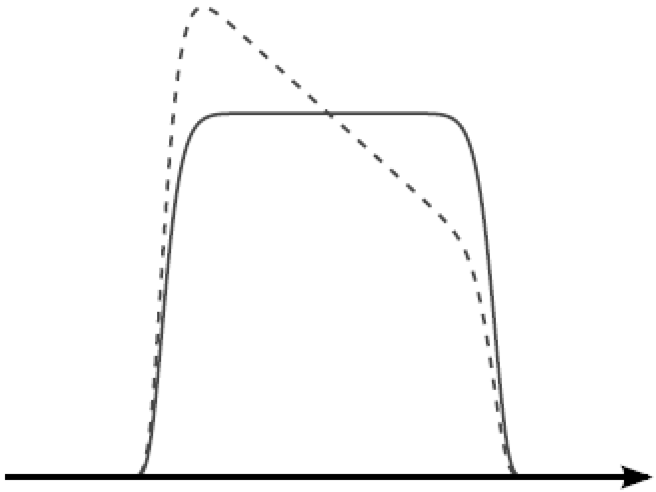
- Request: ellipsoidal, not round
- Fit function: Fermi edge like later replaced by Super-gaussian
- AoI = area, where Super-Gaussian > 90% of maximum

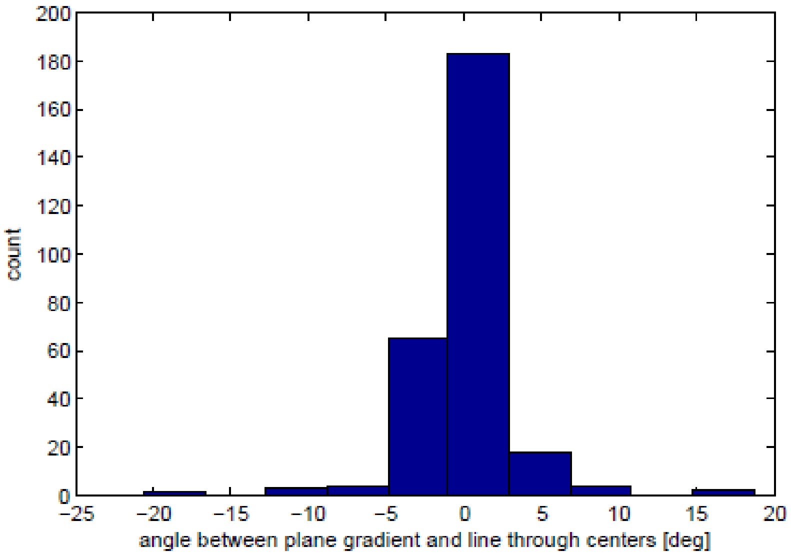




Area of interest – 2D fit

- Issues with asymmetric distributions → fit didn't find parameters
- Try with plane multiplied on Super-gaussian (→possible characterization parameters): solved fitting issue but biased results:

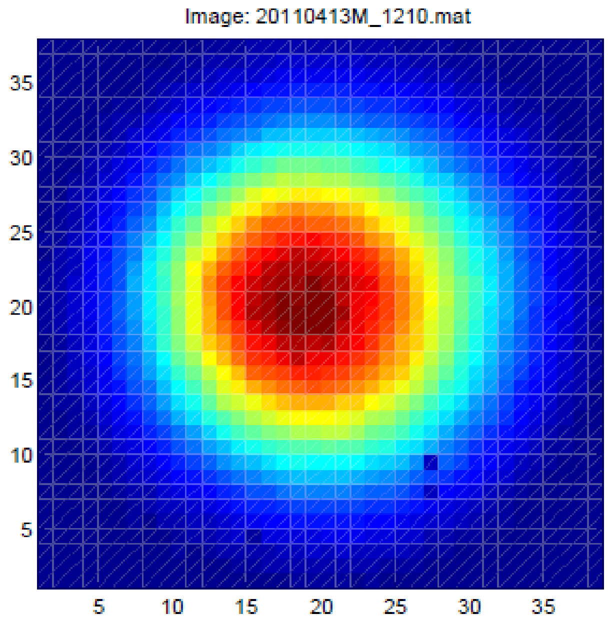


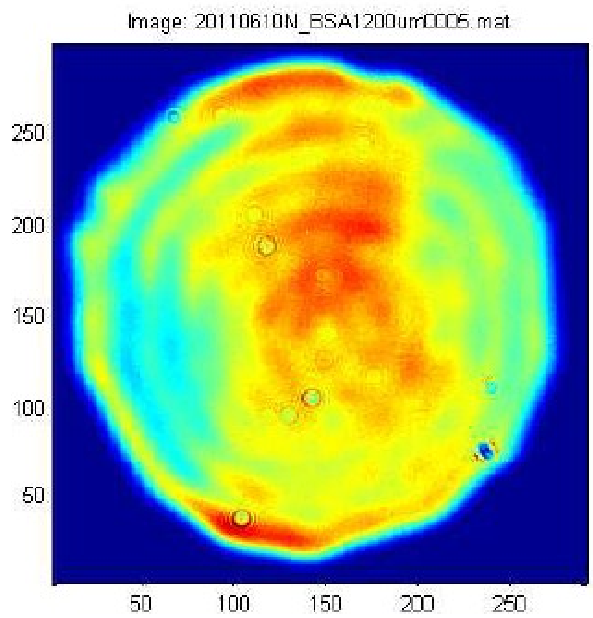


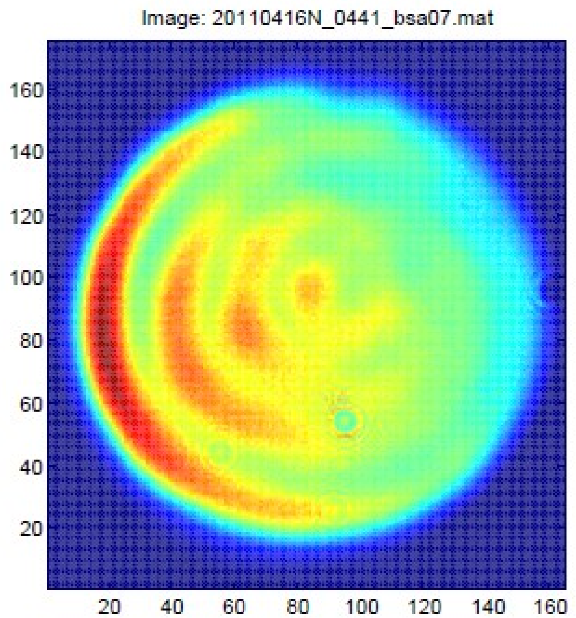
- Issues solved by using non default fitting algorithm (Levenberg-Marquardt instead of trust-region-reflective)

Filtering

- Necessity of filtering out those laser spots that will not work with the algorithm:
  - small BSA spots with non flat-top distribution
  - large BSA spot with inhomogeneous illumination of BSA (though asymmetric illumination should work)

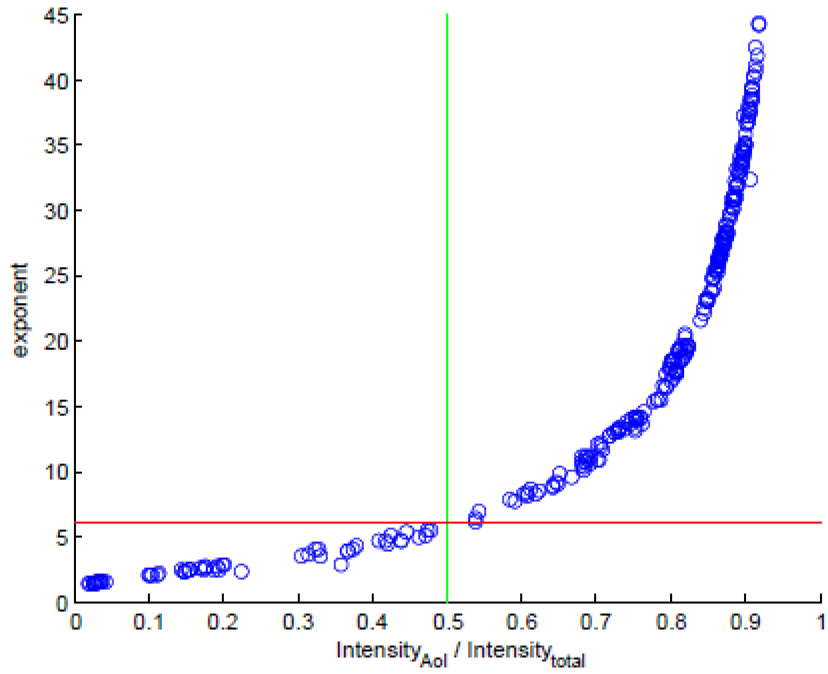






Filtering

- Tried parameters: rms error from fit, χ^2, exponent, BSA size, intensity, $\frac{Intensity_{AoI}}{Intensity_{total}}, \frac{rms\ error}{Amplitude}$
- Only working: $\frac{Intensity_{AoI}}{Intensity_{total}}$ or exponent



Beam characterization parameters

- Parameters: rms error from mean, skew, kurtosis, Intensity, ‘Amplitude’, BSA size, ratio of half axes, $\frac{Intensity_{AoI}}{Intensity_{total}}$

- Spatial correlation (Fusco et al.):

$$\mathrm{cov}(a,h) = \frac{1}{T}\sum_{i=1}^{N}\sum_{j=1}^{M}(a_{ij} - \langle a \rangle)\cdot(a_{ijh} - \langle a \rangle)$$

with

$$a_{ijh} = \frac{1}{(2h+1)^2 - 1}\left[\sum_{l=-h}^{h}\sum_{m=-h}^{h} a_{i+l\,j+m} - a_{ij}\right]$$

$$\begin{pmatrix} a_{i-h\,j-h} & \cdots & a_{i-h\,j} & \cdots & a_{i-h\,j+h} \\ \cdots & & \cdots & & \cdots \\ a_{ij-h} & & a_{ij} & & a_{ij+h} \\ \cdots & & \cdots & & \cdots \\ a_{i+h\,j-h} & & a_{i+h\,j} & & a_{i+h\,j+h} \end{pmatrix}$$

h

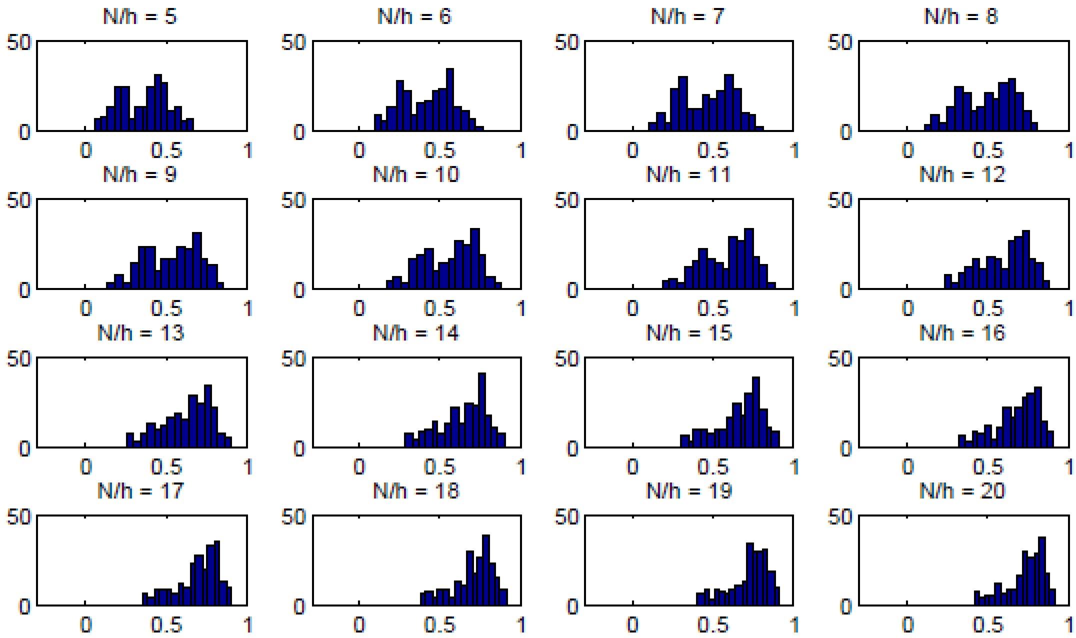
$\rightarrow$

$$\Lambda(a,h) = \frac{\mathrm{cov}(a,h)}{\sigma_a^2}$$

- $\rightarrow$ almost correlation coefficient between a_{ij} and a_{ijh} $\rightarrow$ small difference for larger range of variation (found empirically by Fusco)

Spatial correlation

- Problem: how large should h (='resolution') be?
- Fusco: N/h=20 (resolution relative to spot size)
- PITZ:

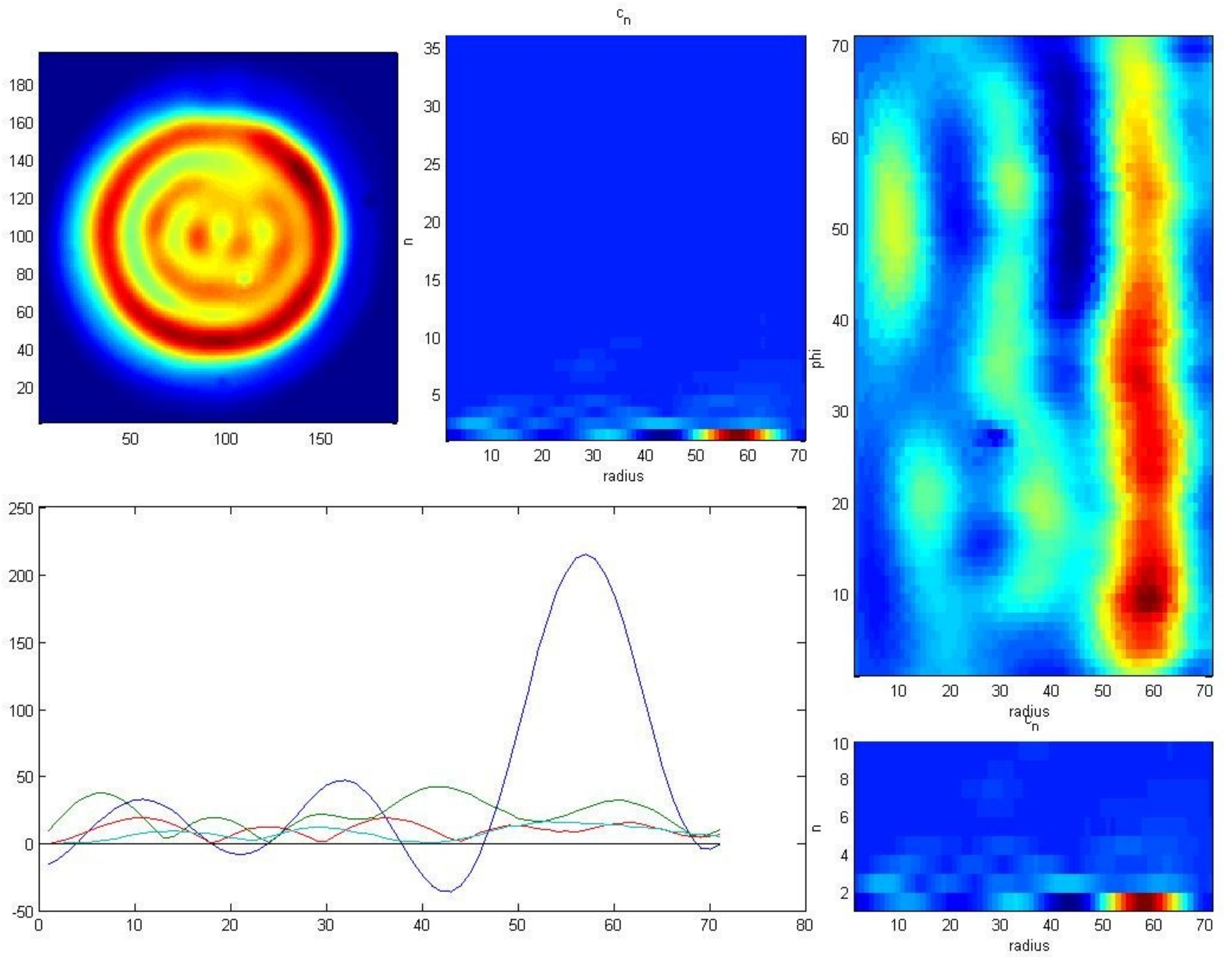


- → broadest distribution (range of variation) with N/h approx. 10, but no decision can be made without simulation or measurement of emittance

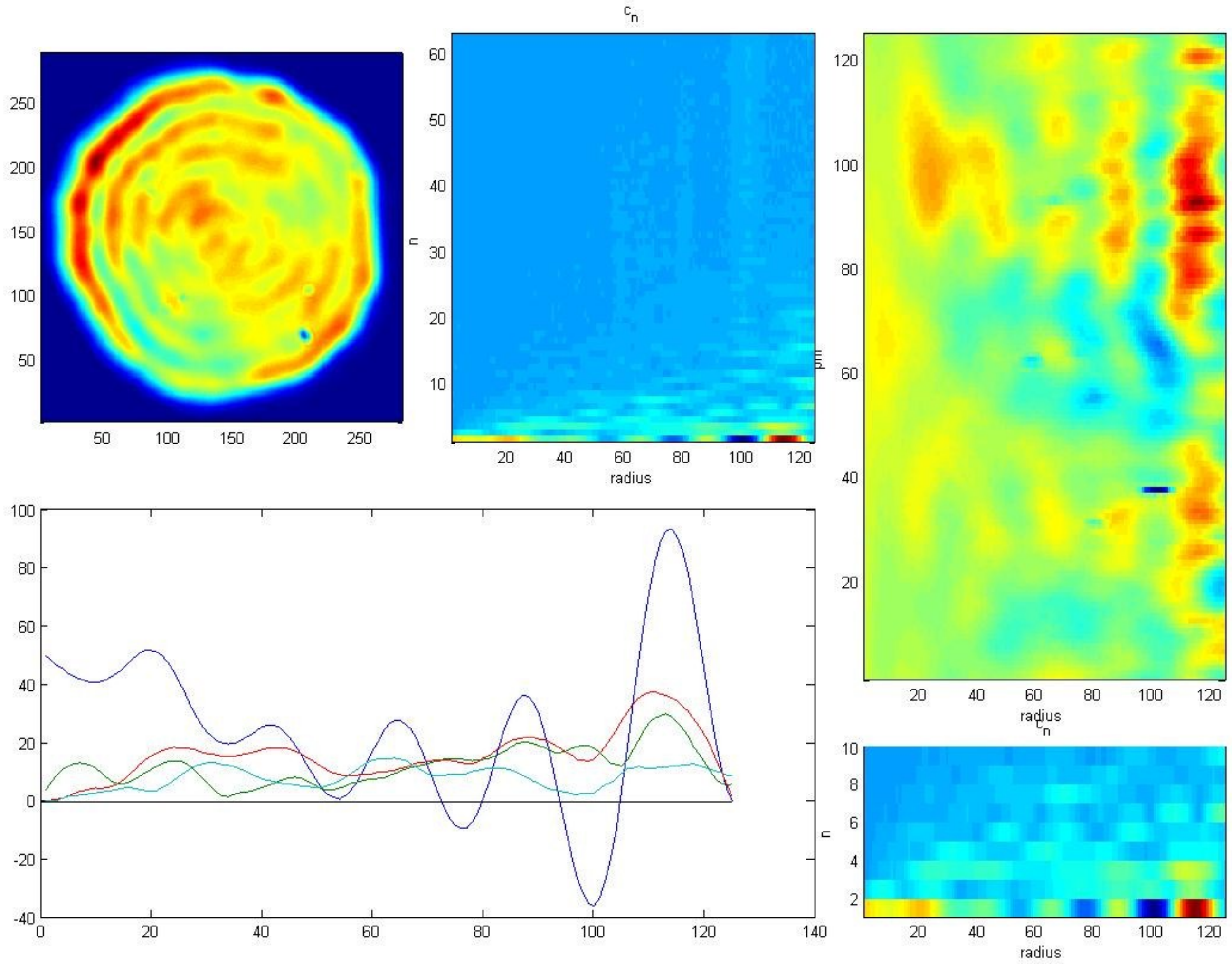
Fourier and Bessel transform

- Transforms of the laser spot in might help analyze the inhomogeneities with only few parameters
- Options: Fourier (diffraction pattern can be explained by Fourier optics) and Bessel functions (due to polar nature of diffraction pattern)
- Necessary: discrete Cartesian to polar coordinates → information loss
- Simple but good enough approach: smoothing of Cartesian spot, then get nearest pixel value for given polar coordinate
- Transform: either Fourier in azimuthal (definitely periodic) angle and Bessel in radius or Fourier in both

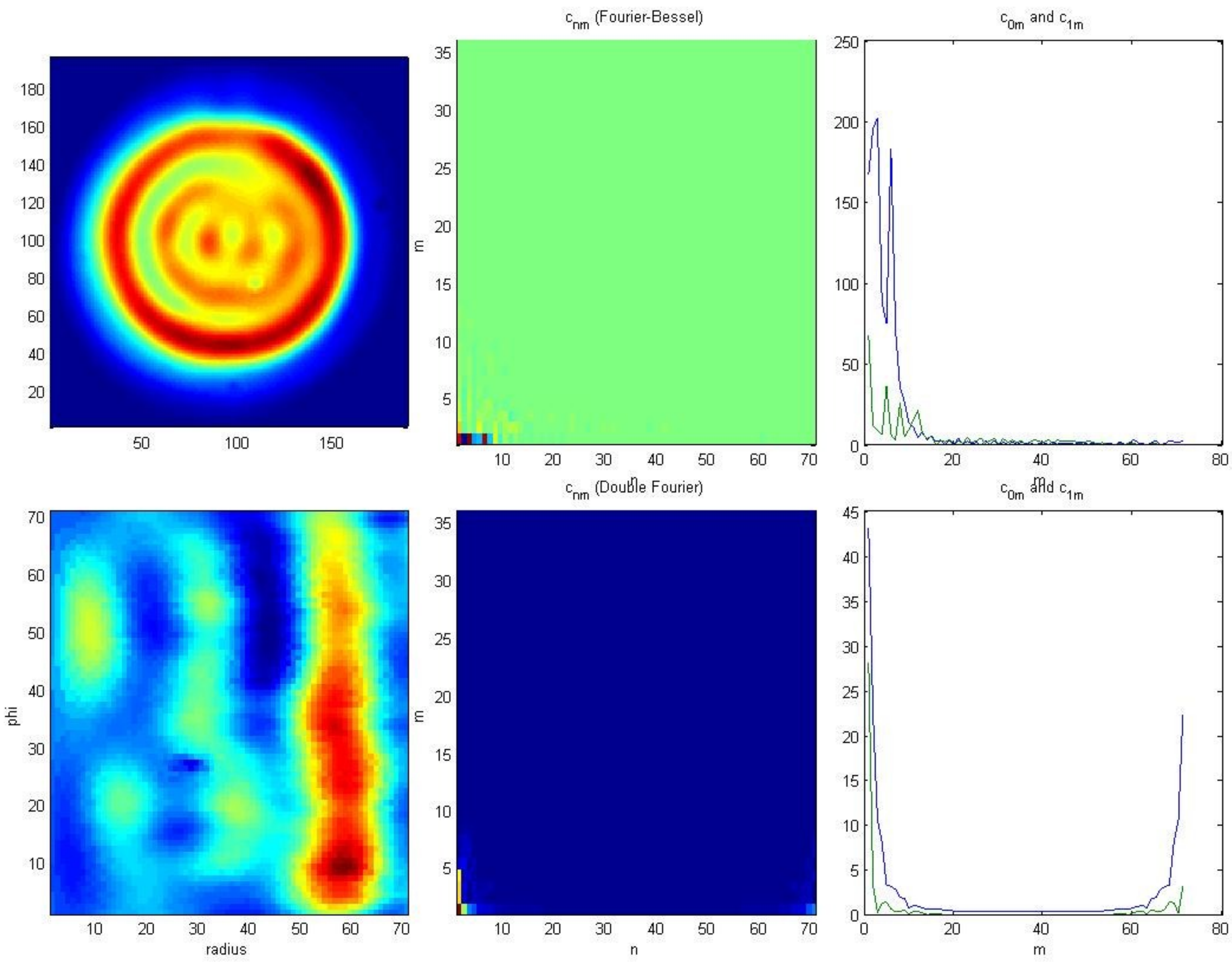
Fourier transform in azimuthal angle only



Fourier transform in azimuthal angle only



Fourier or Bessel transform in radius



Fourier or Bessel transform in radius

- No interesting results, relatively broad spectrum, especially for Bessel function → obviously not good transform function
- No single characterization parameters (e.g. line spectrum) from 2D tranform
- Some interesting results from “1D” Fourier transform

Outlook

- Possible things to investigate from Fourier transform in azimuthal angle:
  - cut of at some frequency and look if back transform reproduces spot well (without noise and low frequency modulations of diffraction features)
  - 2D-> 1D with weighted projection (→ reduction of parameters)
  - Correlation of c_n and c_0 $\rightarrow$ distinguish between diffraction and inhomogeneous illumination of BSA