Measurement of the Transverse Coherence of the Free Electron Laser at the TESLA Test Facility

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Objective

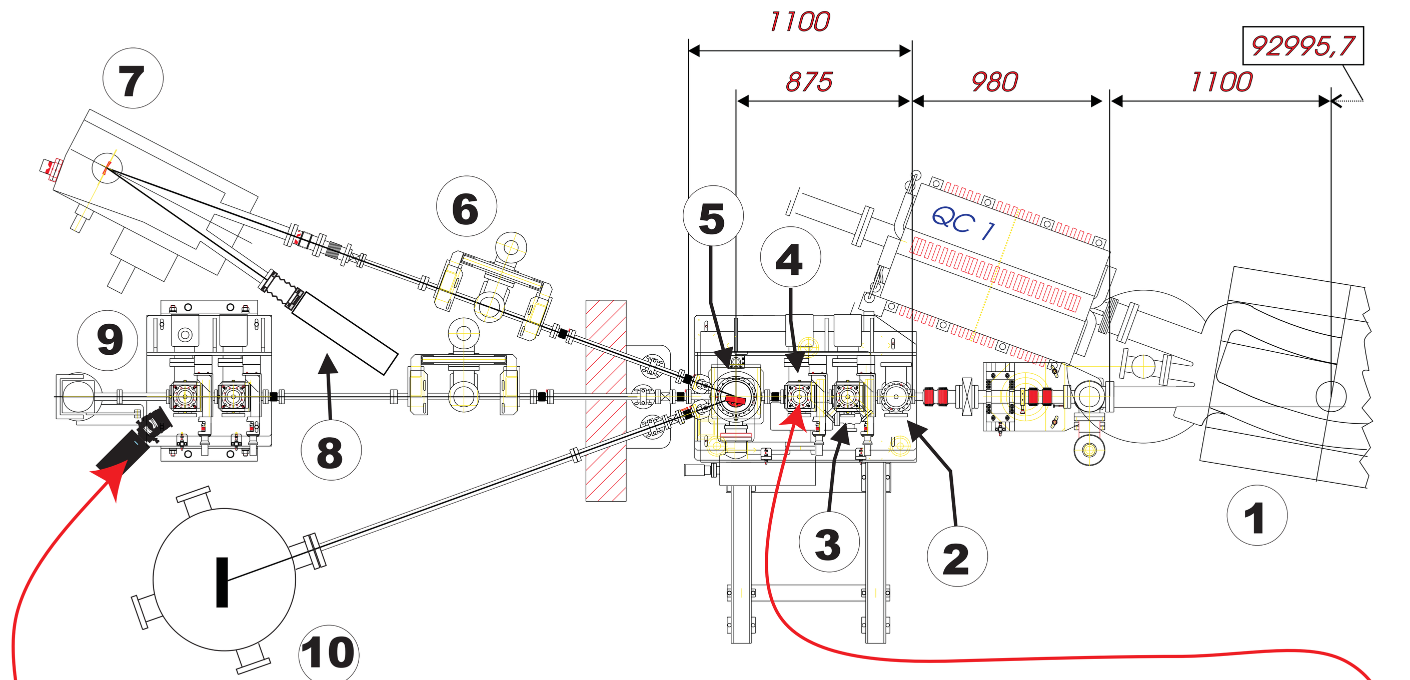
FEL theory predicts that electrons in each mode radiate in phase, i.e. they emit coherent radiation. The transverse coherence was measured with double slits with various separation and crossed slits, as well with circular apertures.

The resulting diffraction pattern is converted to visible light by a CeYAG crystal at a distance of 3.1 m and the image is recorded by a high resolution CCD camera.

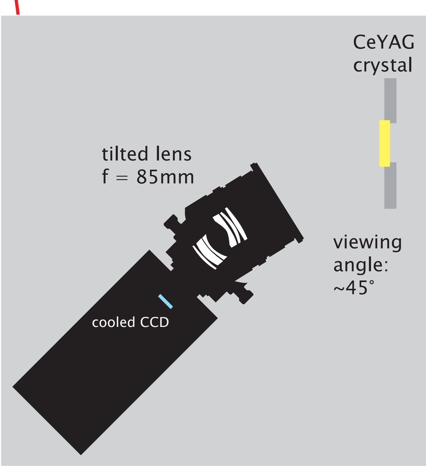
The contrast of this pattern can be used to measure the coherence at the various slit distances. Measurements have been taken at various operating modes and wavelengths of the FEL.

To analyse the images, one has to take into account the fact that the image is not formed in the far field; thus, Fraunhofer diffraction theory cannot be applied. Therefore, a numeric propagation algorithm (GLAD) is used to simulate the diffraction at the slits.

Experimental Set-Up

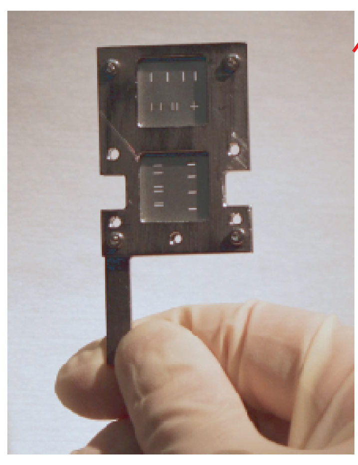


1: bending magnet to deflect the electron beam, 2: alignment laser port, 3: aperture unit, 4: detector and slits unit, 5: deflecting mirror, 6: TSP and ion getter pumps, 7: 1m normal incidence monochromator, 8: CCD-camera, 9: 2nd aperture and detector unit, 10: various experiments



Slit pairs with 0.5 (only horizontal), 1, 2 and 3 mm distance are available. Two stepper motors allow to move the arrangement to the desired position. An additional circular aperture masks off the unwanted slits.

The camera looks on the Cer doped Yttrium Aluminium Garnet (CeYAG) crystal under an angle of approximately 45 degrees. To achieve good focusing over the complete area, the lens is tilted to the optical axis.



Data Acquisition and Processing

The images are transferred via a fibre optical cable to the data acquisition system, located in the control room. They are stored with a synchronized time stamp, allowing for correlations with the data from the accelerator.

Pre-Processing of the images will include:

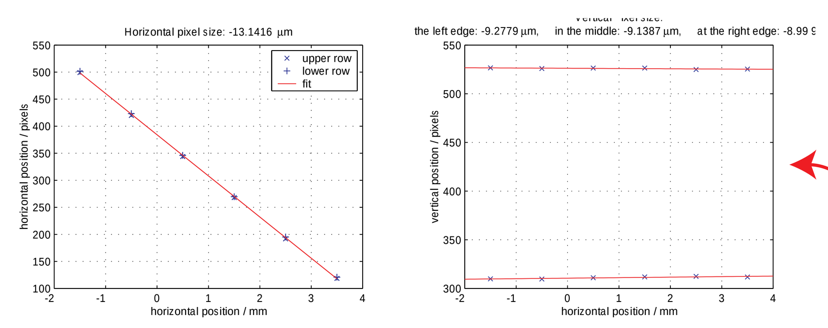
- take into account the response of the screen
- deconvolute with the blur of the imaging system
- take into account the effects of the screen

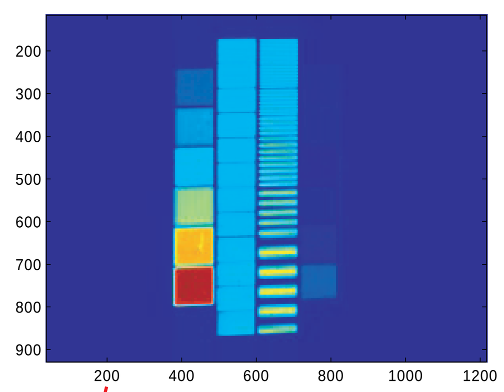
Currently, these steps are not implemented.

Calibration and Resolution

The calibration of the pixel size was done with the images of an aperture at various known positions.

Due to the tilt of the screen to the optical axis of the camera, the vertical pixel size changes across the image. The horizontal resolution is regarded as constant.

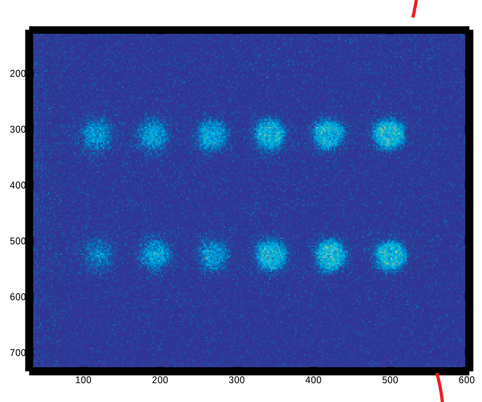




To estimate the blurring effects of the screen and the lens, two known objects were imaged:

a screen equipped with sine wave modulated fields, illuminated by an ordinary tungsten lamp.

the image of a circular aperture directly in front of the screen, illuminated by the FEL. This takes into account the effects of the screen as well.

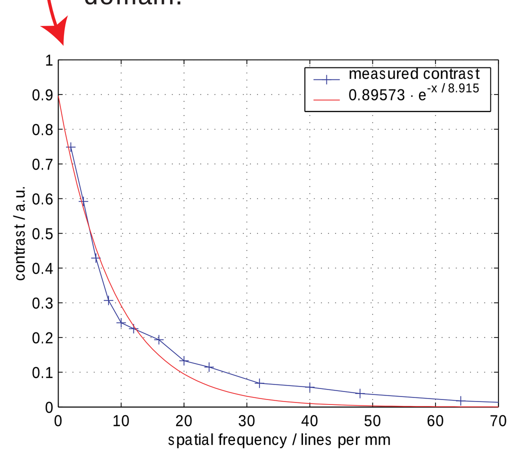


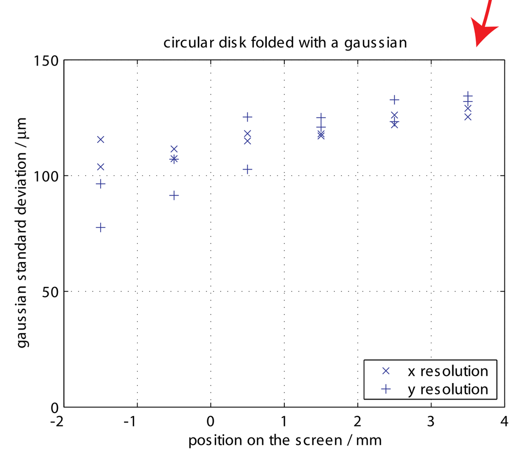
The observed contrast of the sine wave patterns decreases with a higher spatial frequency.

The decrease is approximated by an exponential curve, which corresponds to a Lorentz-shaped resolution function in the spatial domain.

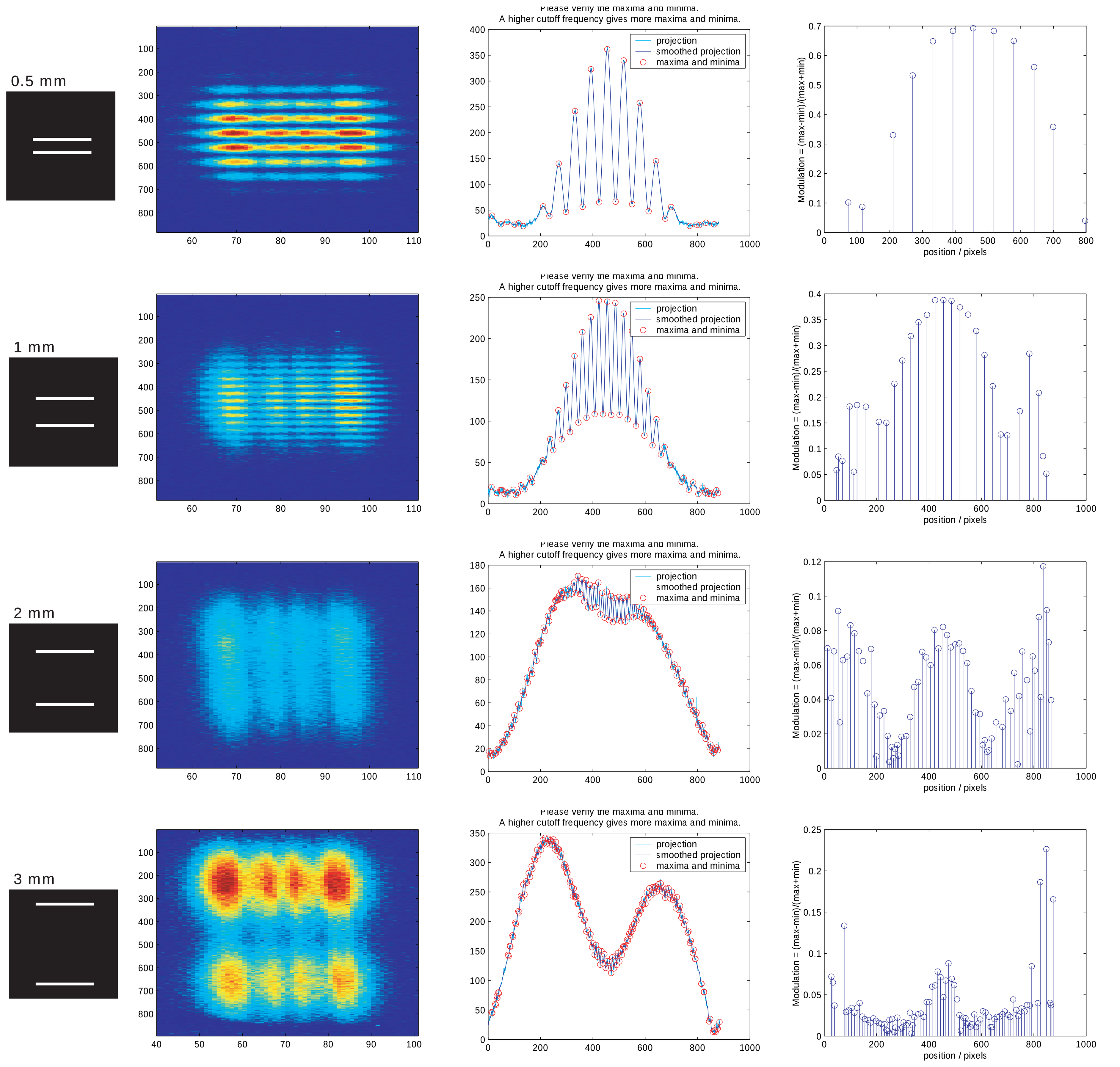
A circular disk of the predicted size, convoluted with a two-dimensional Gaussian was fitted to the images.

The standard deviation of the gaussian is around 100 um, much higher than expected.





Double Slit Interference Patterns



The following analysis steps were done:

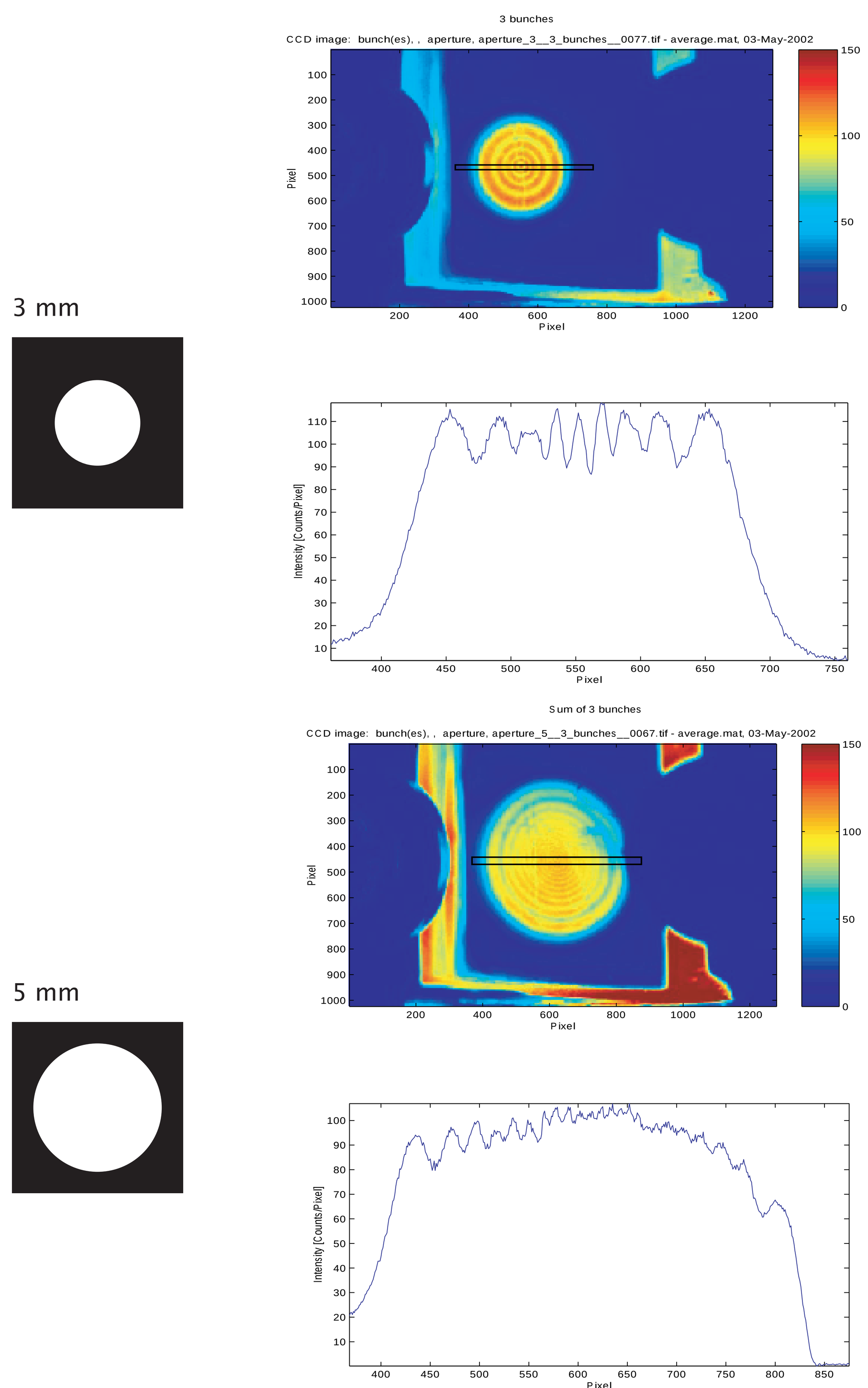
- project along horizontal direction
- smooth the curve with a butterworth filter
- find maxima and minima of the smoothed curve
- for each maximum: determine the modulation

$\zeta = (max+min)/(max-min)$

(Use the mean of the two adjacend minima)

Note: due to the finite length of the slits, there is also a diffraction pattern in horizontal direction.

Circular Apertures



The circular apertures create a ring pattern on the screen.

The number of these so-called Fresnel rings can be calculated in the near field using:

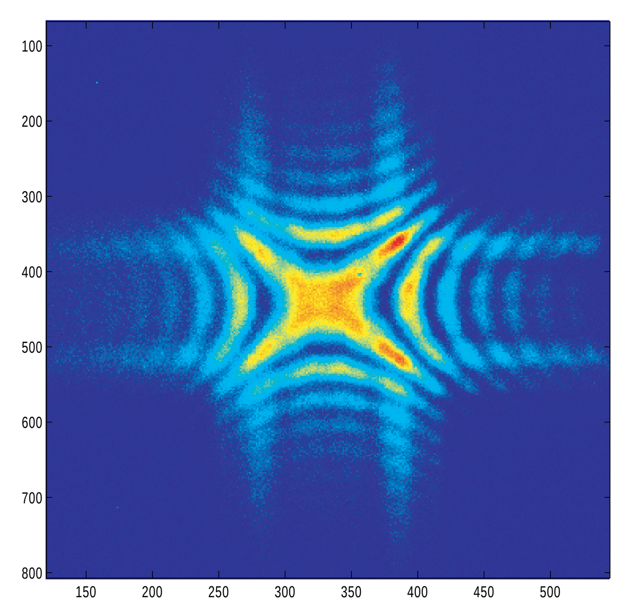
$$N_f = \frac{r^2}{\lambda}\left(\frac{1}{D} + \frac{1}{L}\right)$$

where r is the radius of the aperture, D the distance between source and aperture and L the distance between aperture and screen.

In our case, we find:

aperture	predicted N_f	observed N_f
3 mm	9.2	9
5 mm	25.5	24

Crossed Slits



In principle, the crossed slits can be regarded as double slits with varying distance.

One could try to track the modulation along the diagonal.

Open Questions

What is the response curve of the screen? Does it show saturation?

What is the effect of averaging several images?

What is the resolution of the screen and the imaging system? Can we unfold the images with this resolution function?

Why does the modulation decrease towards the outer parts of the image and then increase again?

What can we extract from the images of the circular apertures?

How can we process the crossed slits?

How does the coherence depend on the accelerator parameters? How does it change along the undulator?

More Information

...can be obtained from our web site (available only within the DESY network):

http://hasy361.desy.de/www/

TESLA — TeV Energy Superconducting Linear Accelerator