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ATF

Sub-micrometer resolution transverse electron beam size measurement system based on optical transition radiation

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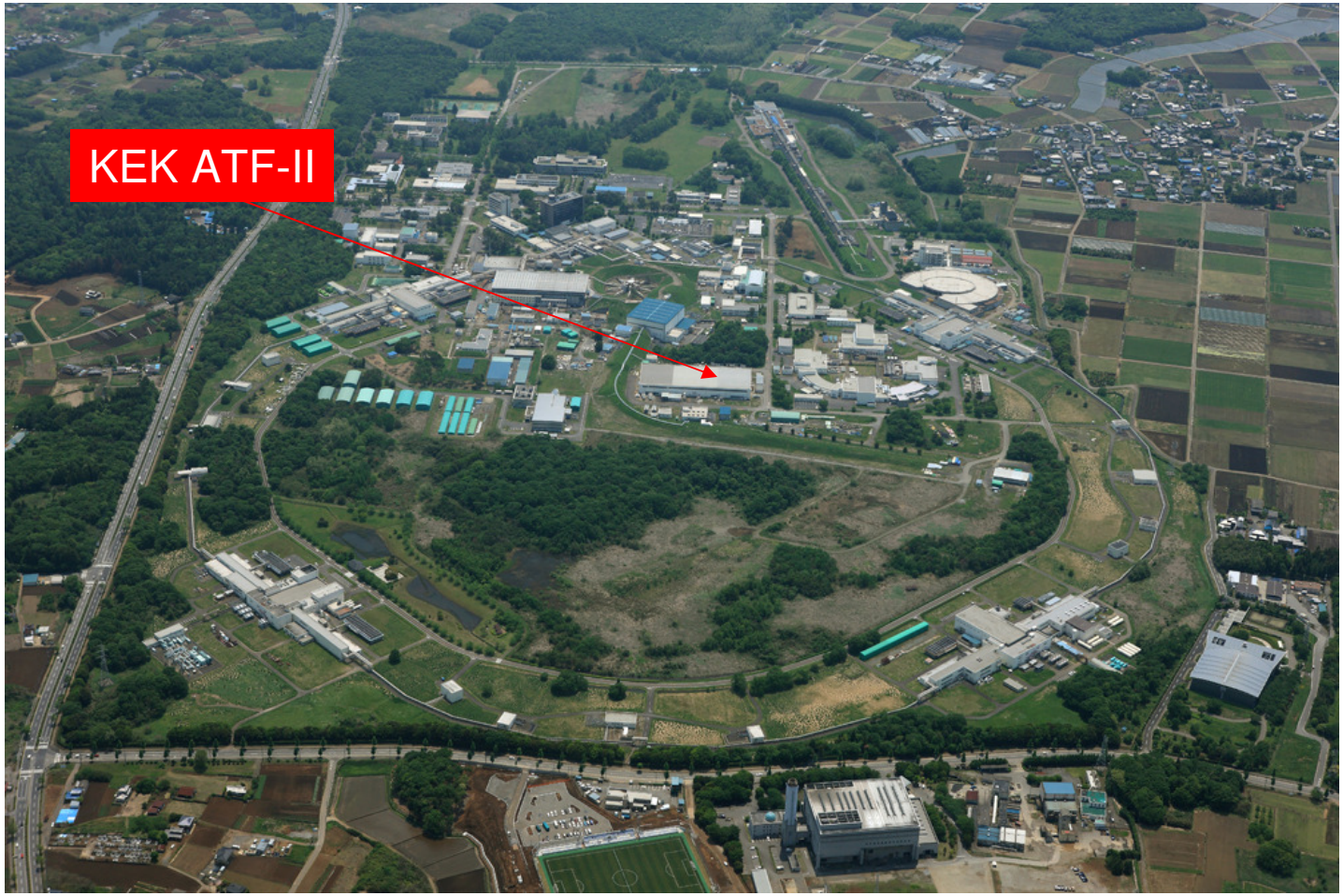
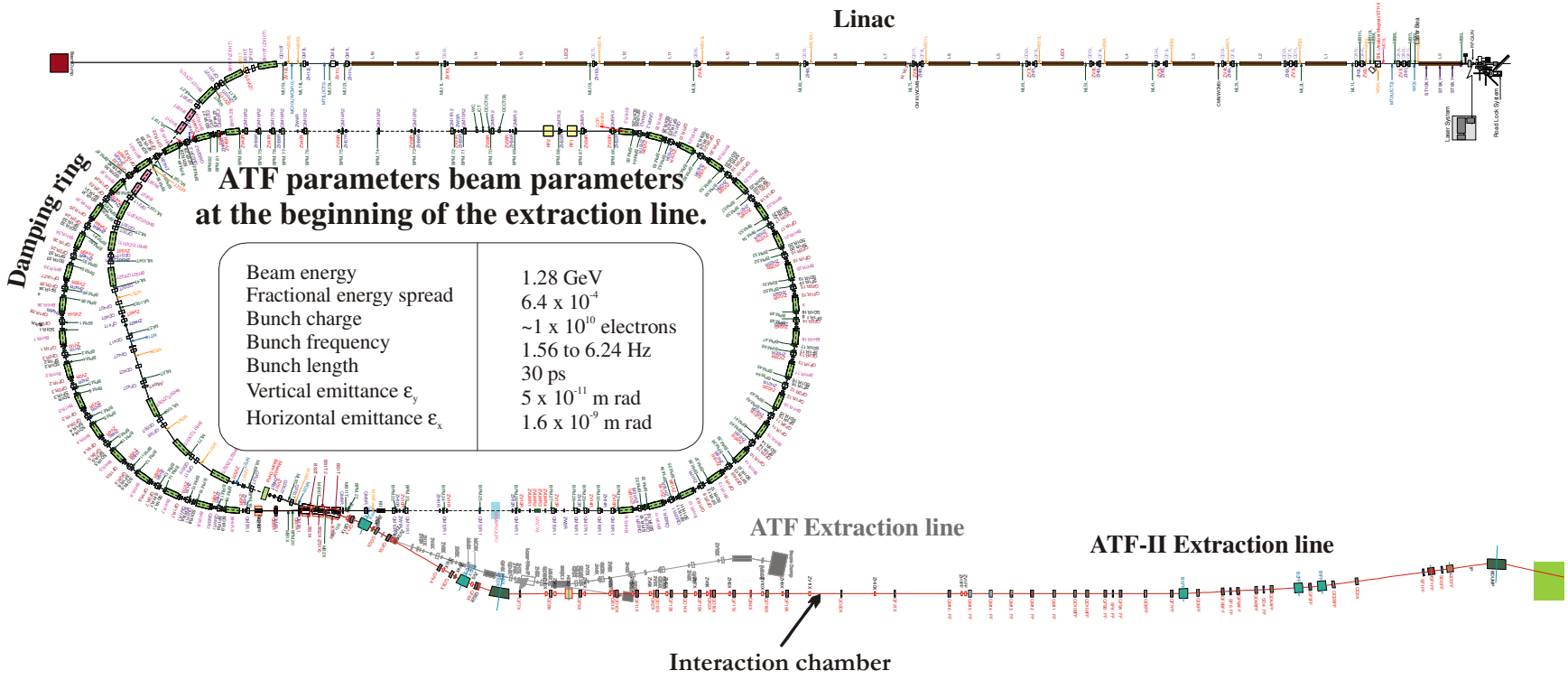
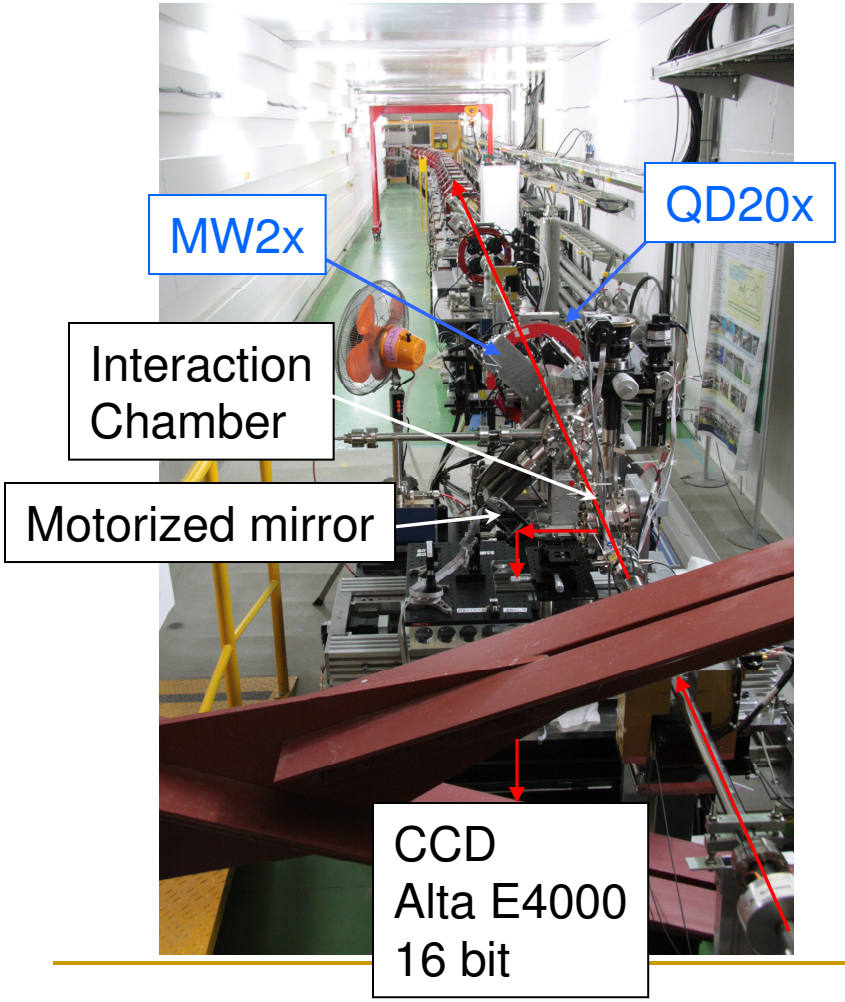
Introduction

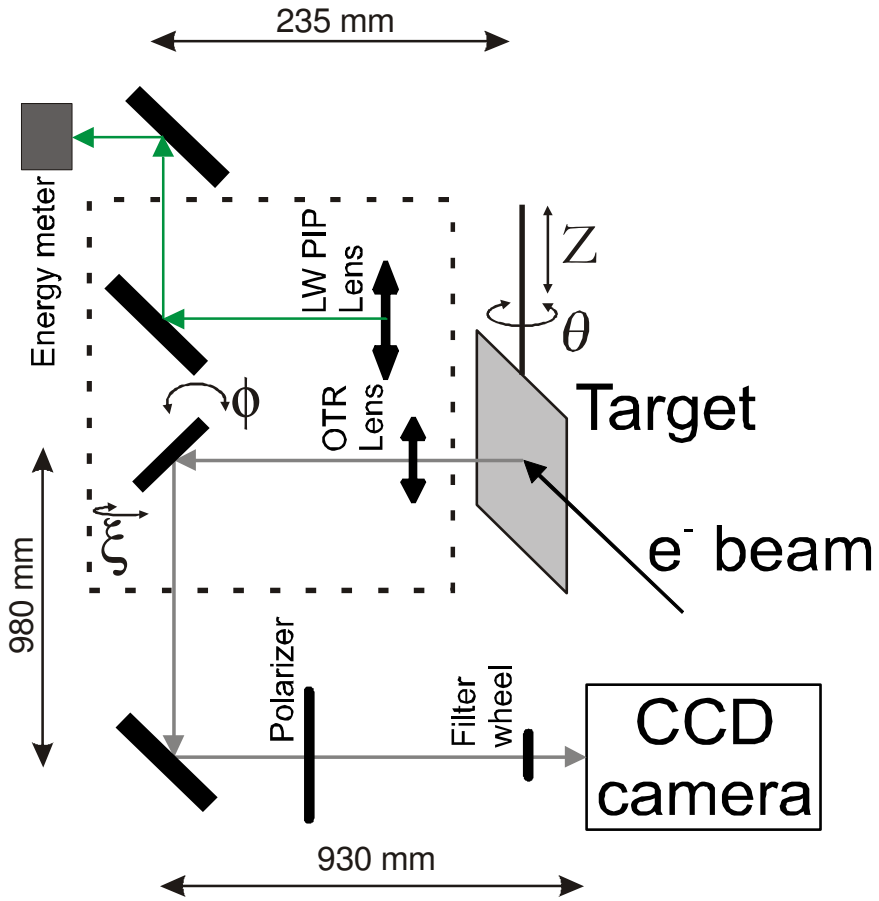


KEK ATF-II, beam parameters



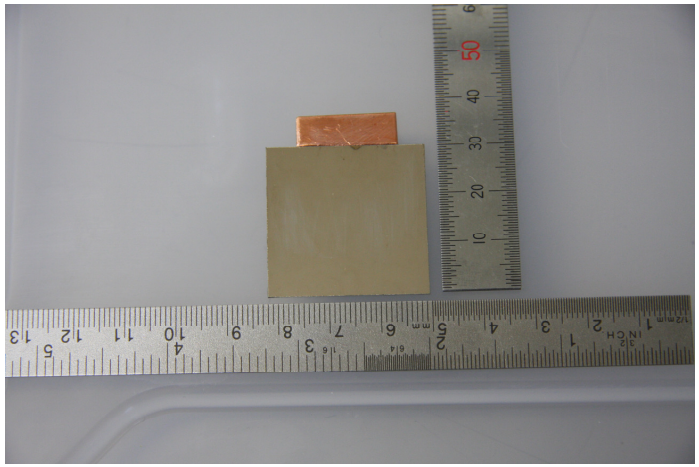
ATF-II beam line, OTR setup

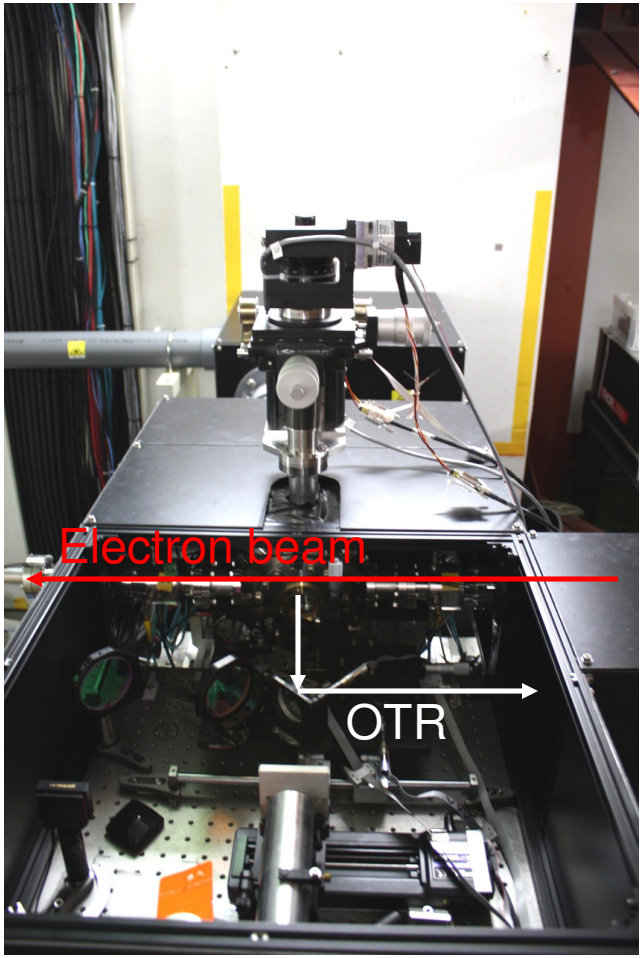




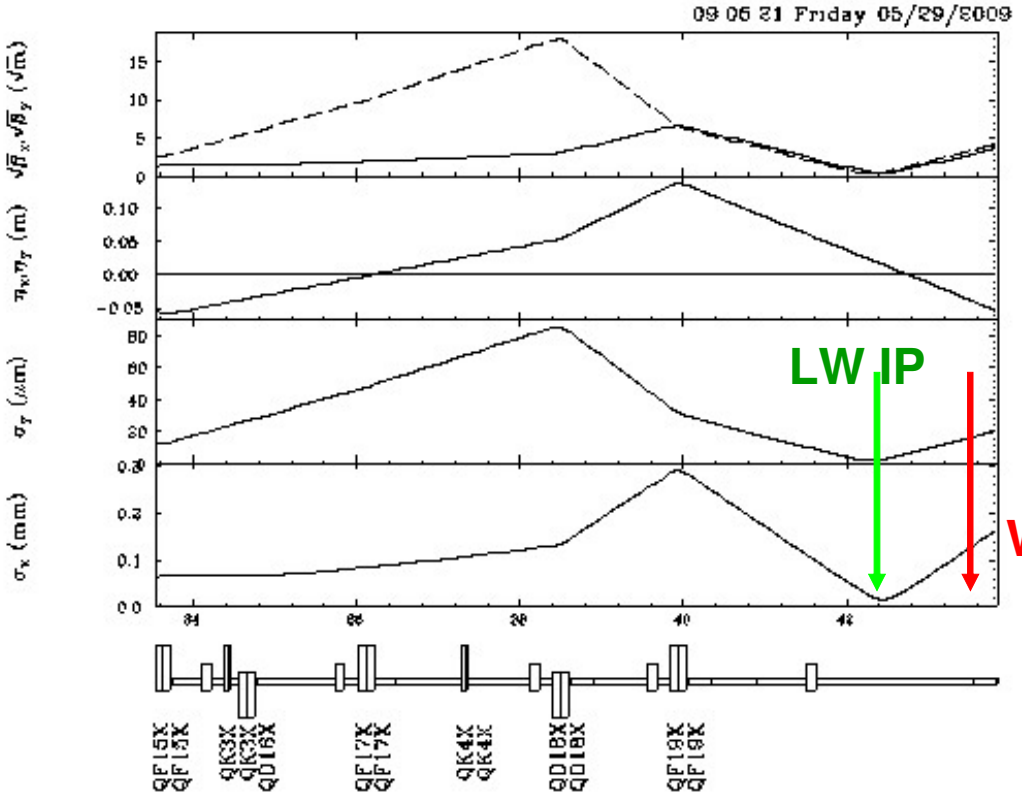
Interaction Chamber, OTR line

Si substrate coated with Al
30x30x0.3 mm





Electron beam optics



- Predictions:

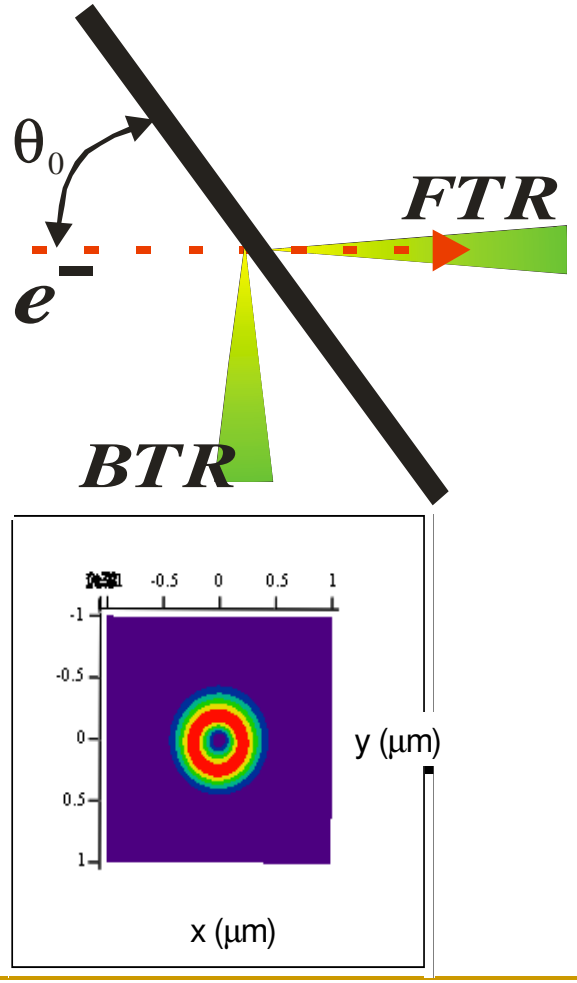
	at LW IP	at MW2X
σ_x	20μm	20μm
σ_y	1.7μm	2.3μm

- Measurements at MW2X

σ_x = 30μm

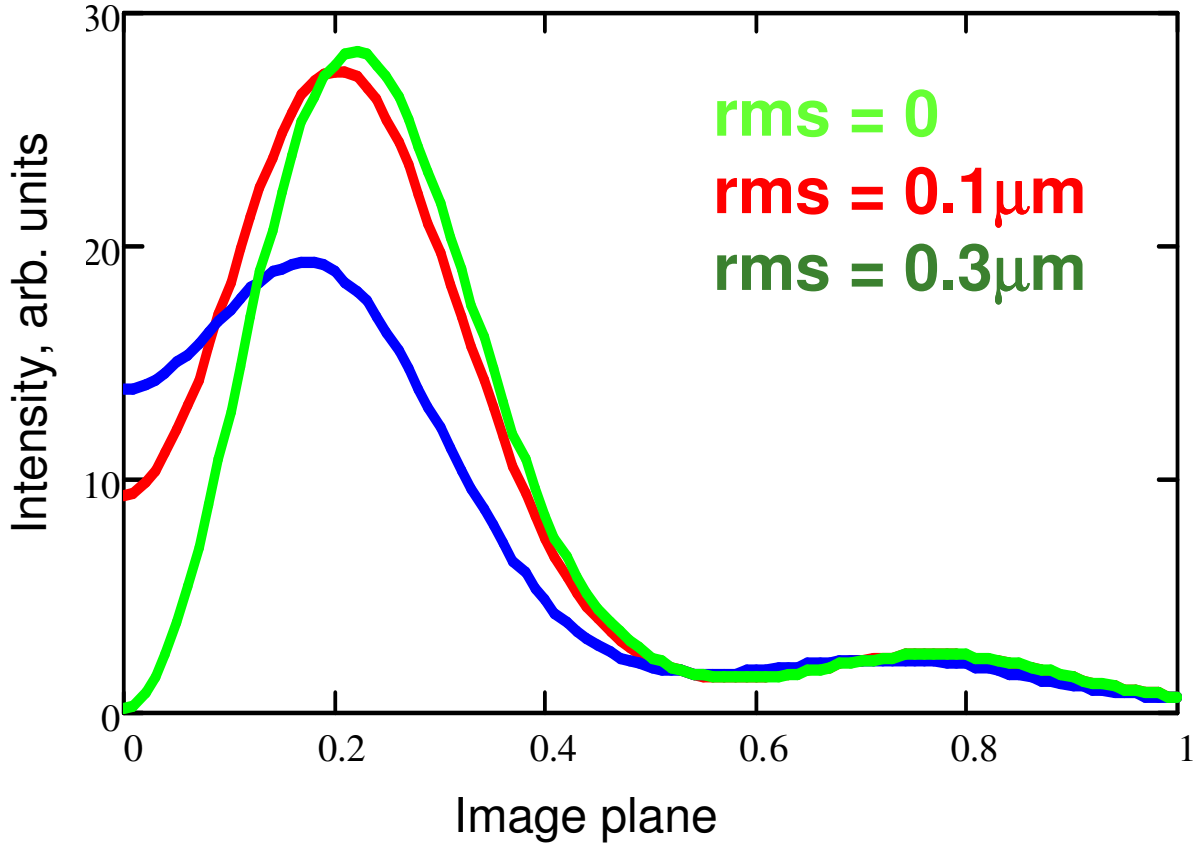
σ_y = 3.4μm

Optical Transition Radiation

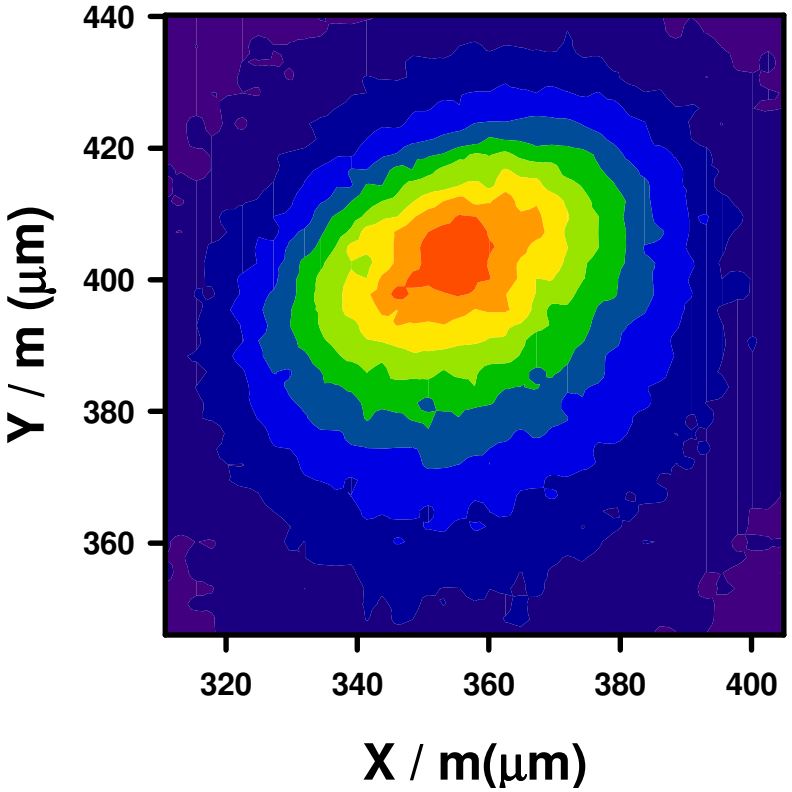


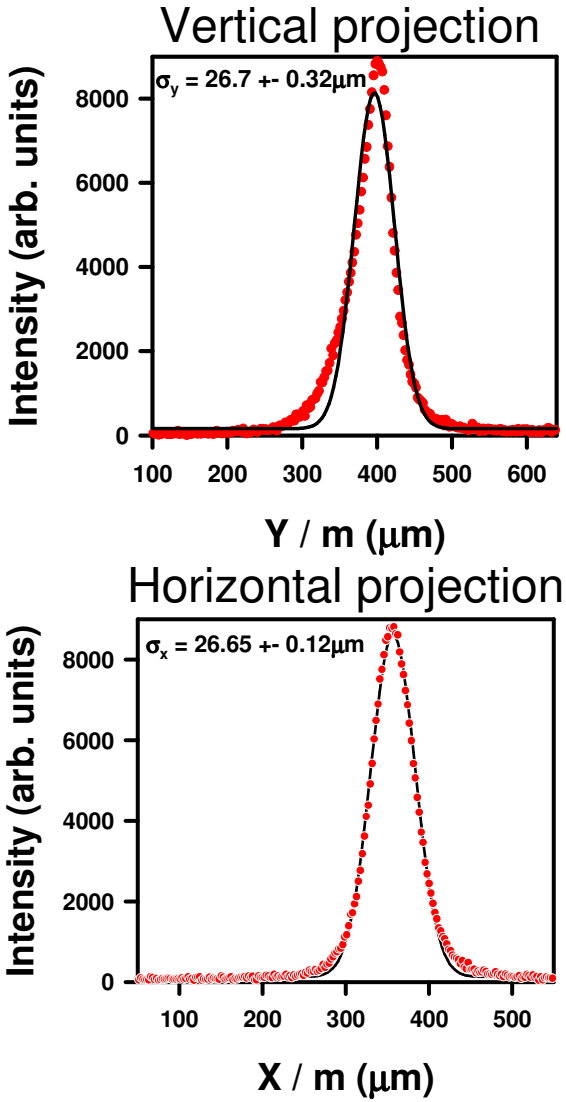
- Transition radiation (TR) appears when a charged particle crosses a boundary between two media with different dielectric constants.
- The resolution is determined by the source dimensions induced by a single particle plus distortion caused by the optical system (diffraction of OTR tails)

Beam size effect

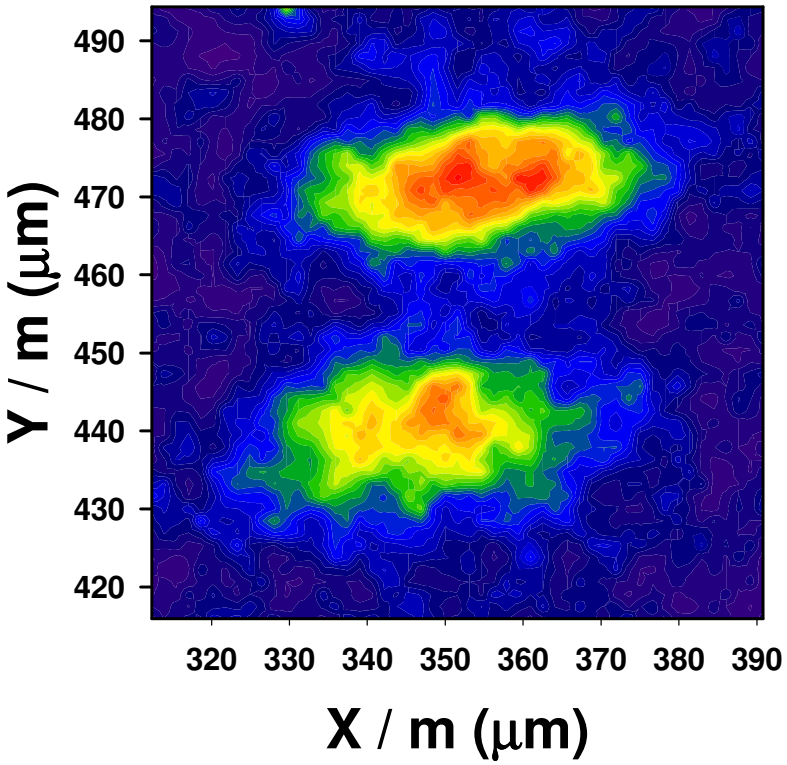


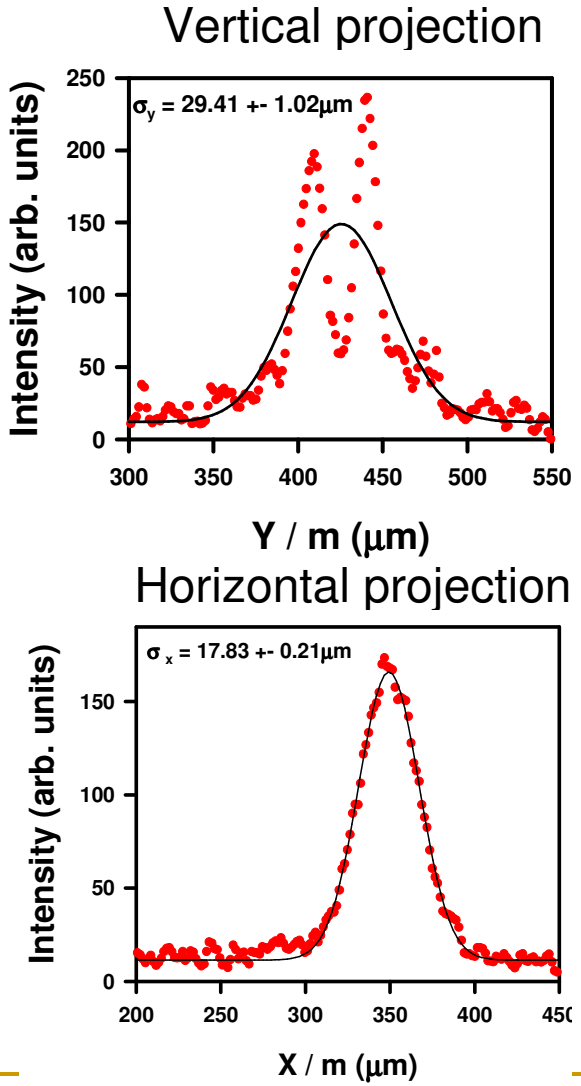
OTR image with NO filter and polarizer



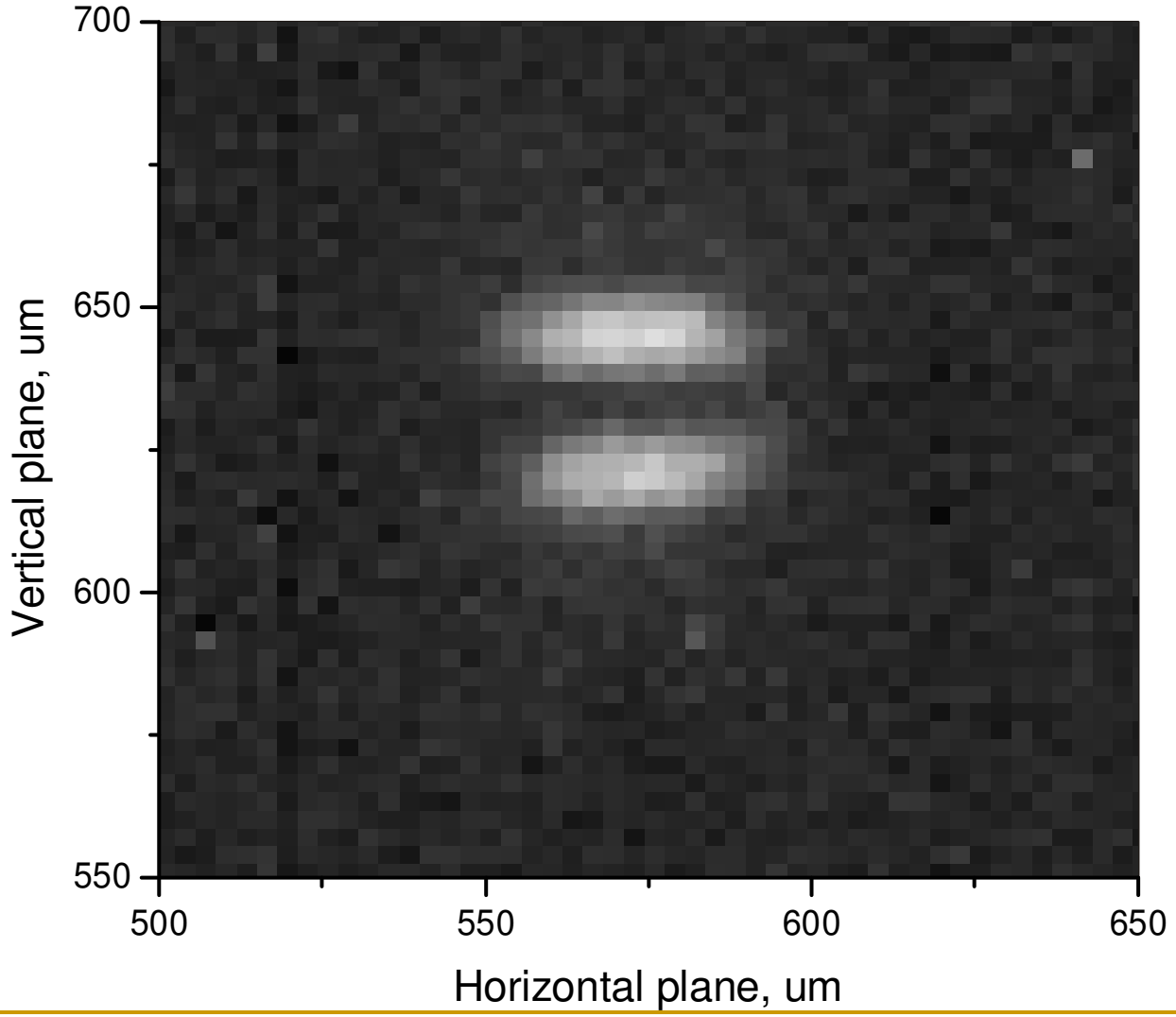


OTR image with polarizer and optical filter

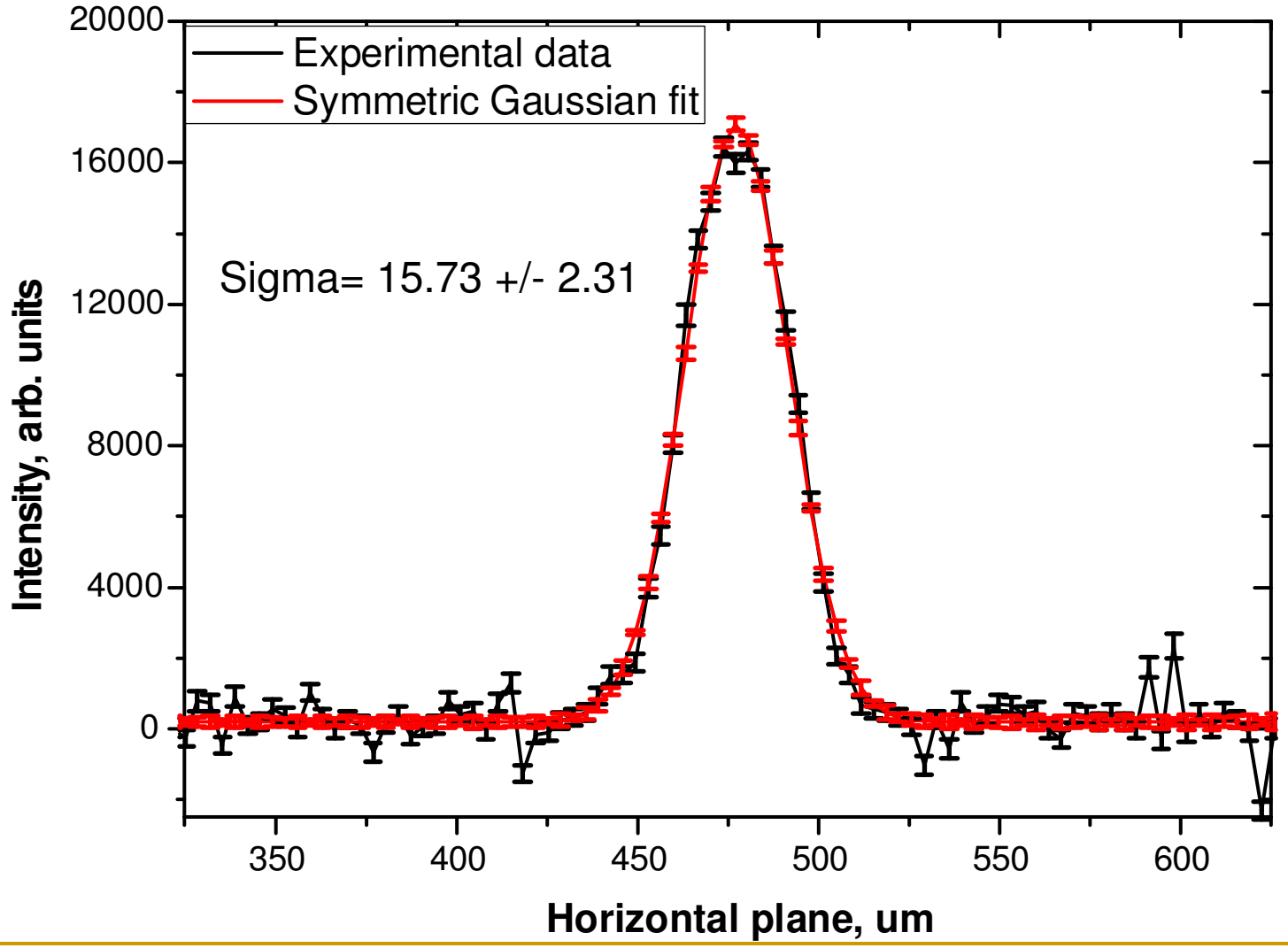




OTR image


700
650
600
550
Vertical plane, um
500
550
600
650
Horizontal plane, um

Horizontal projection

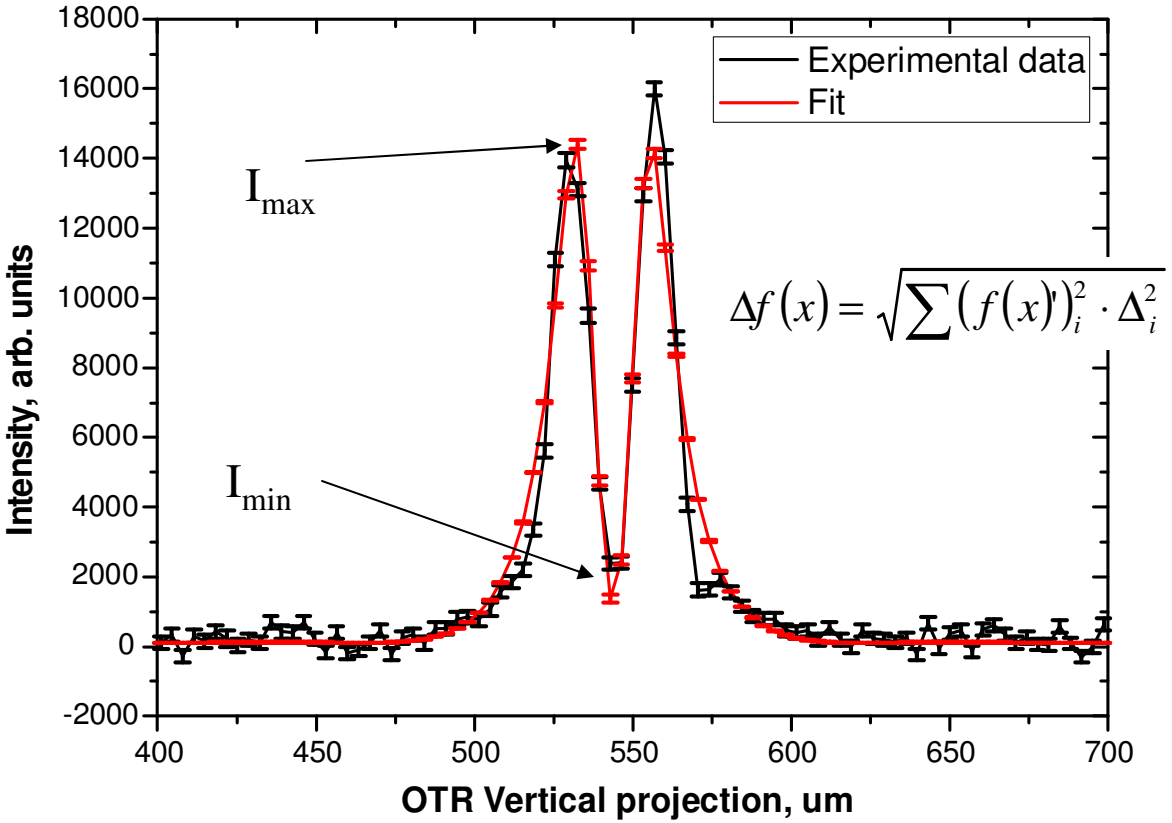


OTR PSF-like Fit function

$$f(x) = a + \frac{b}{1+[c(x-\Delta x)]^4}\left\{1 - e^{-2c^2\sigma^2}\cos[c(x-\Delta x)]\right\}$$

a	143.034 +/- 80.2691
b	60440.8 +/- 175.643
c	0.0807 +/- 0.00165
Δx	543.838 +/- 0.18656
σ	2.36213 +/- 0.59153

Here *a*, *b*, c, σ, and Δx are free parameters of the fit function;
- *a* is the vertical offset of the distribution with respect to zero.
- *b* is responsible for the amplitude of the distribution;
- c is responsible for the distribution width;
- σ is the smoothing parameter dominantly defined by the beam size;
- Δx is the horizontal offset of the distribution with respect to zero.



$$\Delta f(x) = \sqrt{\sum (f(x)')_i^2 \cdot \Delta_i^2}$$

Self-Calibration procedure

- In the whole data set find a file with smallest $I_{\min} / I_{\max}$
- Calculate error of the ratio

$$\Delta_{I_{\min}/I_{\max}} = \sqrt{\sum \left(_{I_{\min}/I_{\max}}'\right)_i^2 \cdot \Delta I_i^2} = \sqrt{\frac{\Delta I_{\min}{}^2}{I_{\max}{}^2} + \frac{I_{\min}{}^2 \cdot \Delta I_{\max}{}^2}{I_{\max}{}^4}}$$

- Re-generate fit curve *f(x)* with errors *Δf(x)* for the calibration file substituting zeros for horizontal and vertical offsets *(a,c)* and σ.

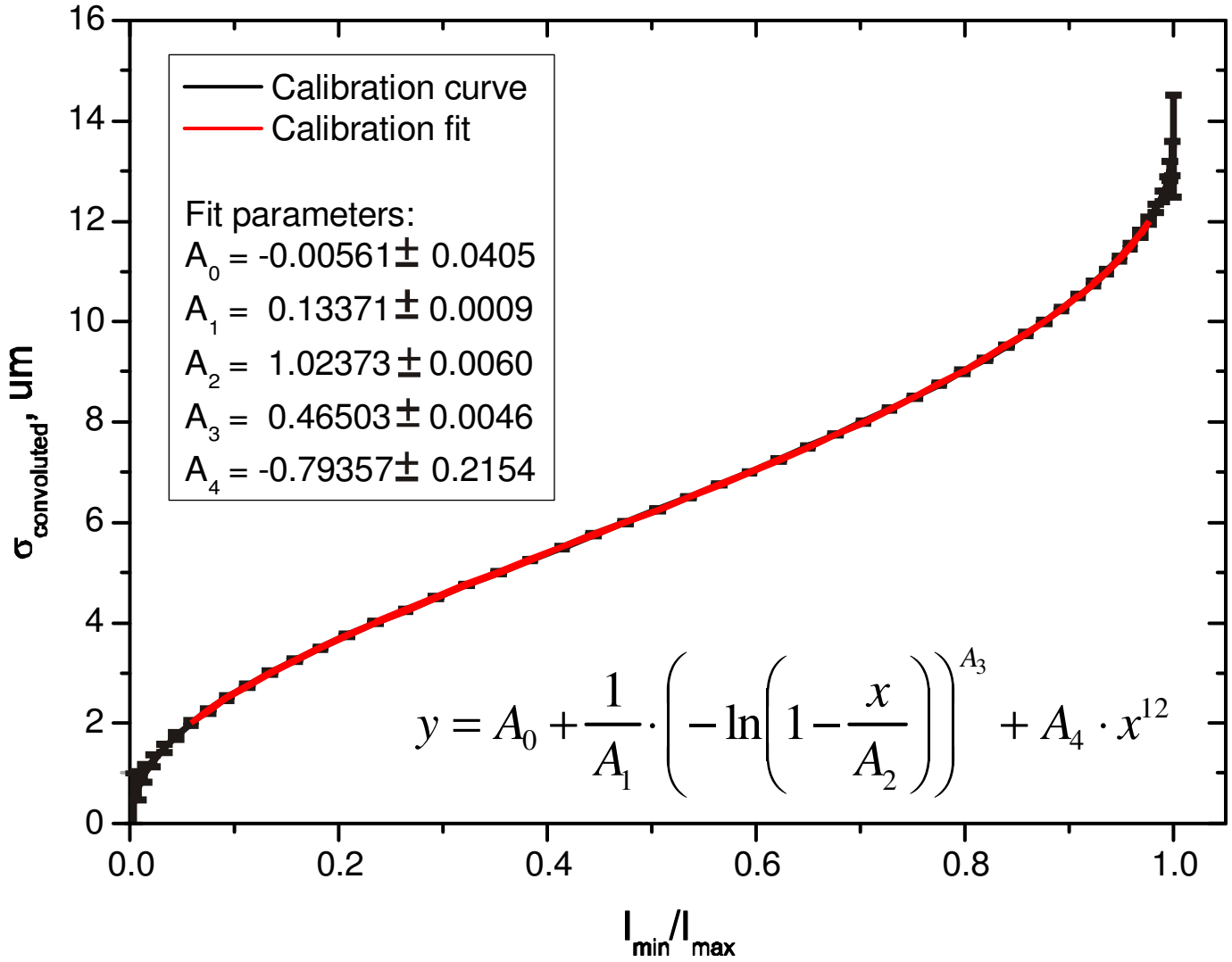
Self-Calibration procedure

- Convolute it with Gaussian as follows:

$$F_j^{Convolution} = \frac{\sum_{i=1}^{N} f_i(x_i) \cdot \exp\left(\frac{-(x-x_i)^2}{2\sigma_{conv}^{\ 2}}\right)}{\sum_{i=1}^{N} \exp\left(\frac{-(x-x_i)^2}{2\sigma_{conv}^{\ 2}}\right)}$$

- Propagate errors $\Delta f(x)$ through convolution according to (2), repeat convolution N times varying σ_{conv} from 0 to M with a fine step.
- For each iteration, find $I_{\min} / I_{\max}$ and calculate its errors resulting in calibration curve.

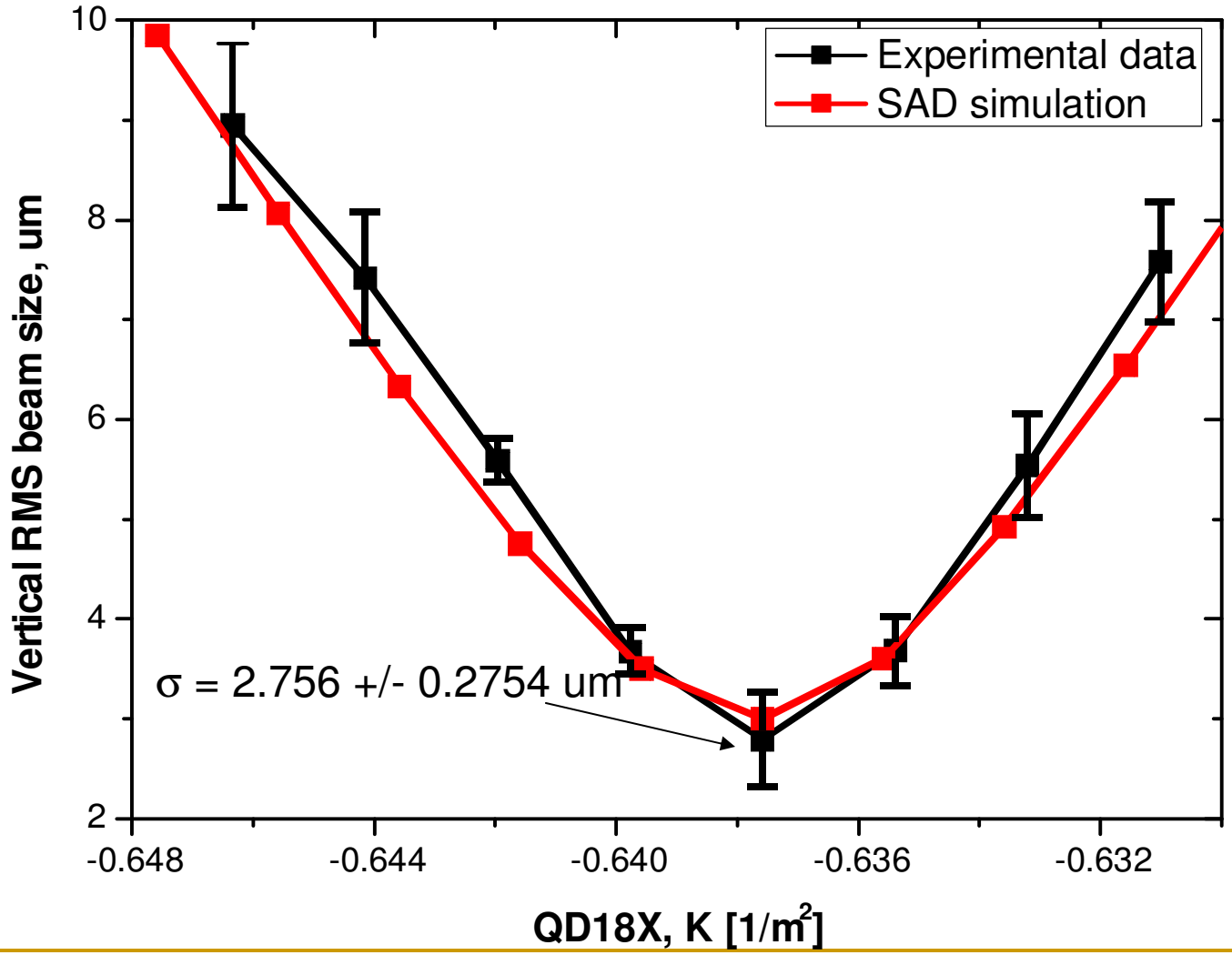
Calibration curve



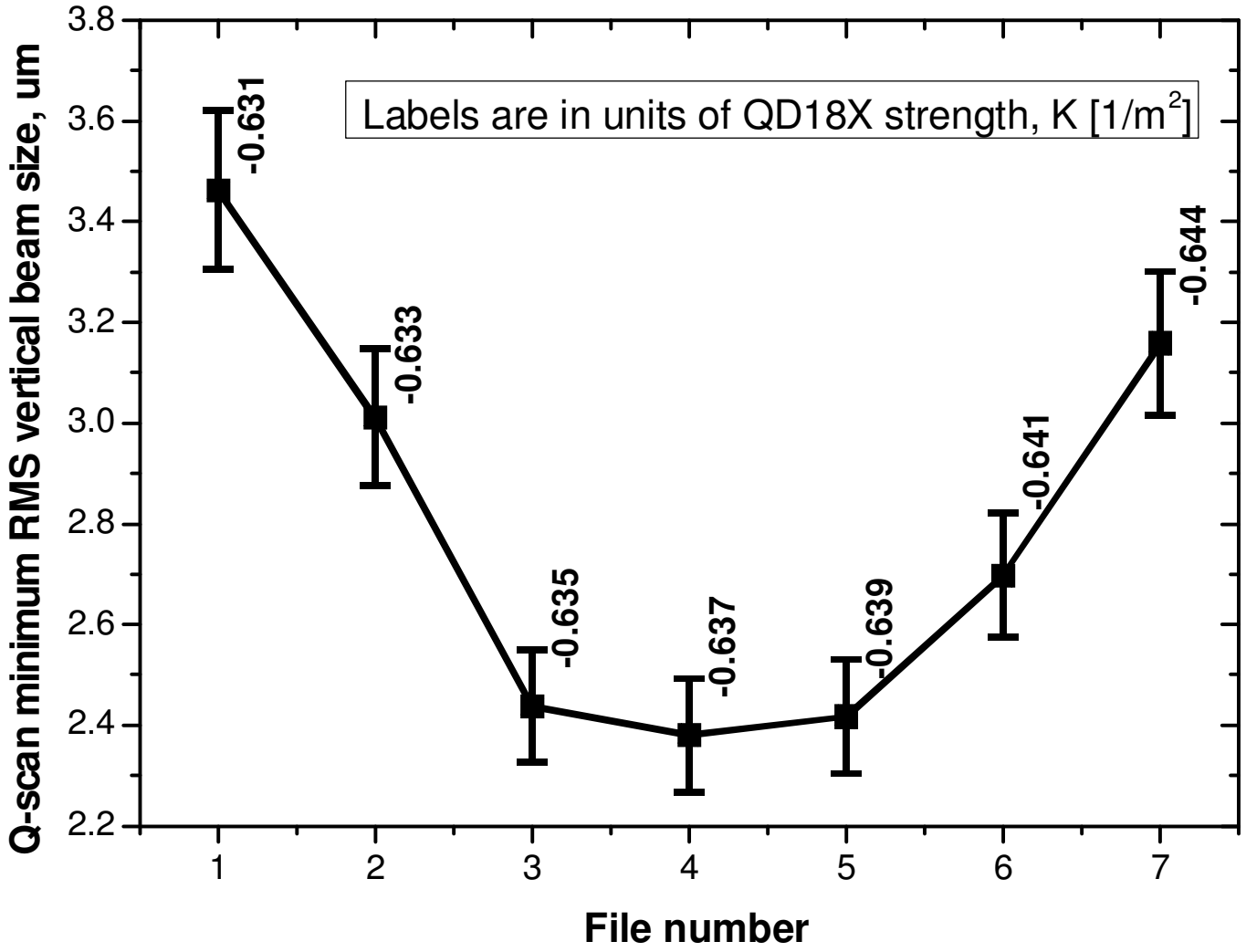
Self-Calibration procedure

- Propagate errors through calibration fit.
- Analyze all files in a data set, extracting $I_{\min} / I_{\max}$ and $\Delta_{I_{\min} / I_{\max}}$ for each file and convert it to real vertical RMS beam sizes using calibration fit parameters and its standard deviations.

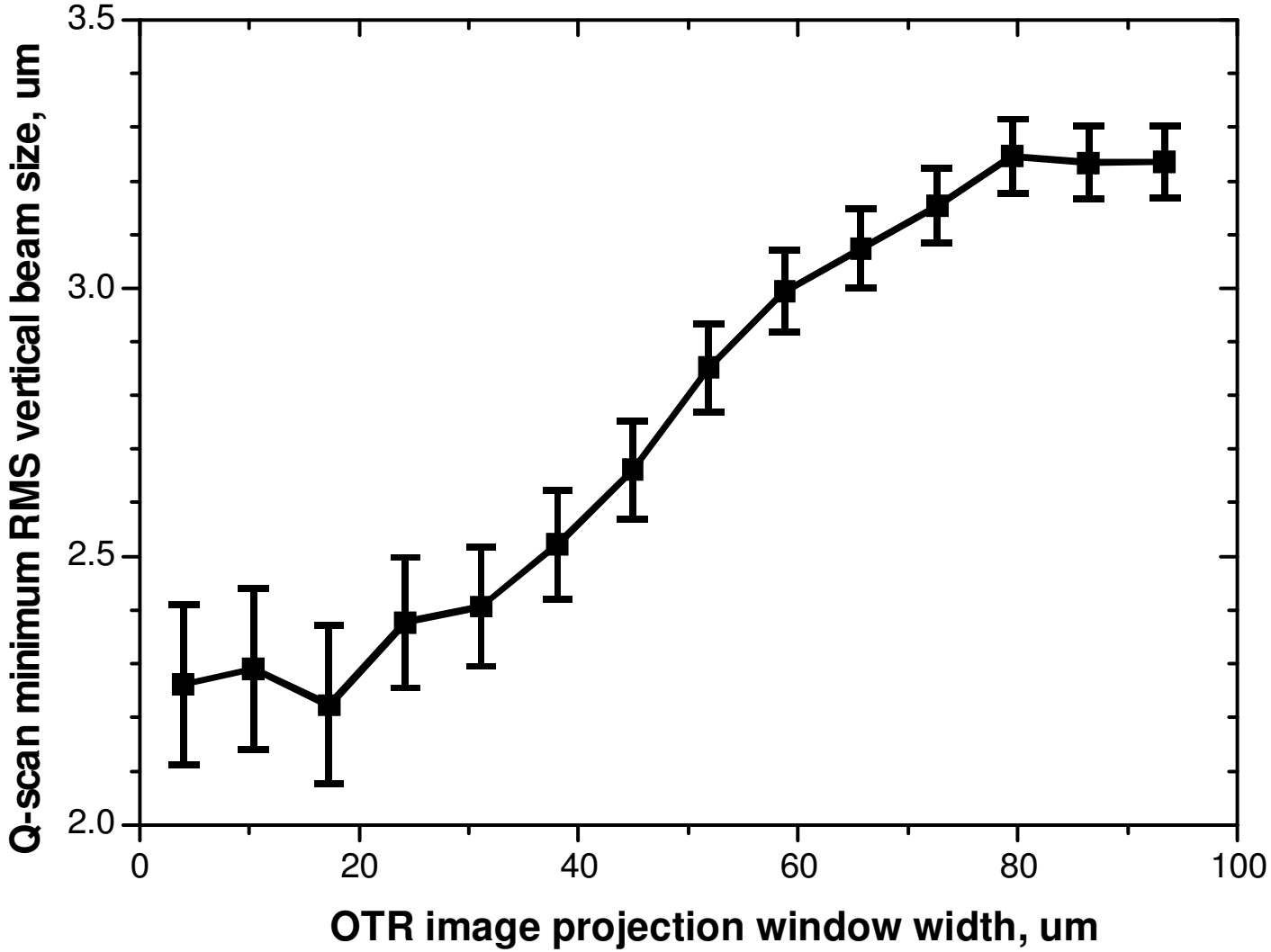
Reconstructed Q-scan



Calibration file variation



Cursors gap variation



Summary

- Results clearly demonstrate that the method based on the analysis of the PSF structure visibility gives an opportunity to measure the beam size with a sub-micrometer resolution.
- In order to improve the beam size measurement technique additional efforts toward the optimization of the optical system, and better understanding of the beam size effect has been taken.
- To be able to demonstrate better resolution achromat lens (to minimize the chromatic aberrations in the optical system) was employed.

Summary

- Also a few more optical filters covering the wavelength range from 350 to 800nm with 50nm step was used to investigate the spectral characteristics of the OTR PSF in details.
- The results will be represented in a successive paper.

Acknowledgements

We would like to thank the ATF extraction line Laser-Wire collaboration for giving us an opportunity to conduct the experiment.

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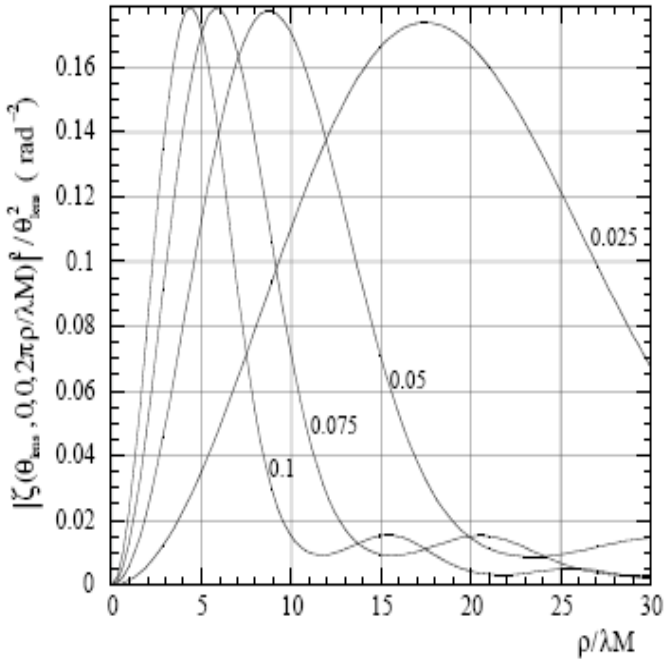
Phenomena leading to PSF distortion

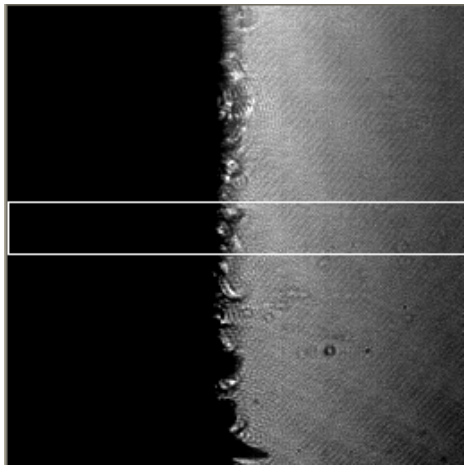
- Diffraction of OTR tails
- Chromatic aberrations
- Spherical aberrations

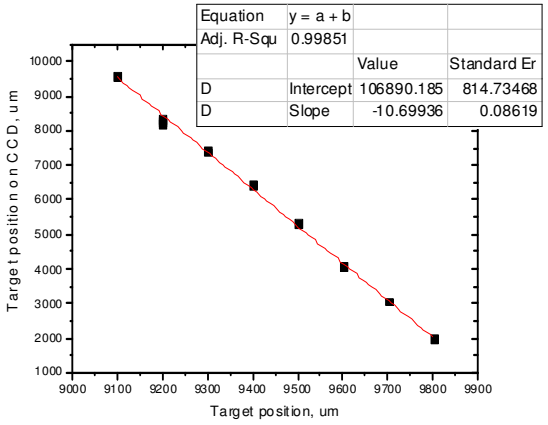
for instance, M. Castellano and V.A. Verzilov, Phys.Rev. ST-AB 1, 062801 (1998)



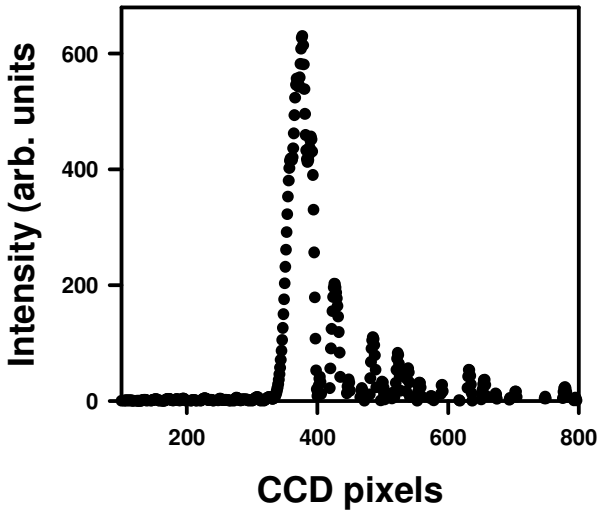
Calibration of the optical system

CCD Image of the target edge





Differentiated slope



Magnification factor of an optical System 10.69