Extremely Low Emittance Beam Size Diagnostics with Sub-Micrometer Resolution Using Optical Transition Radiation

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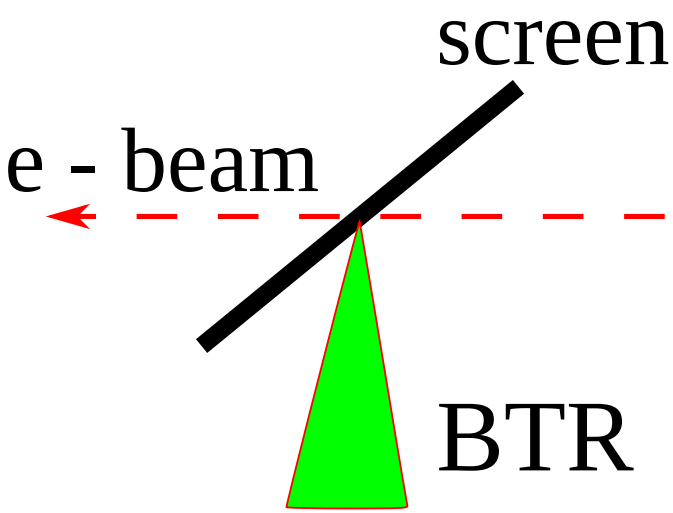
Outlines

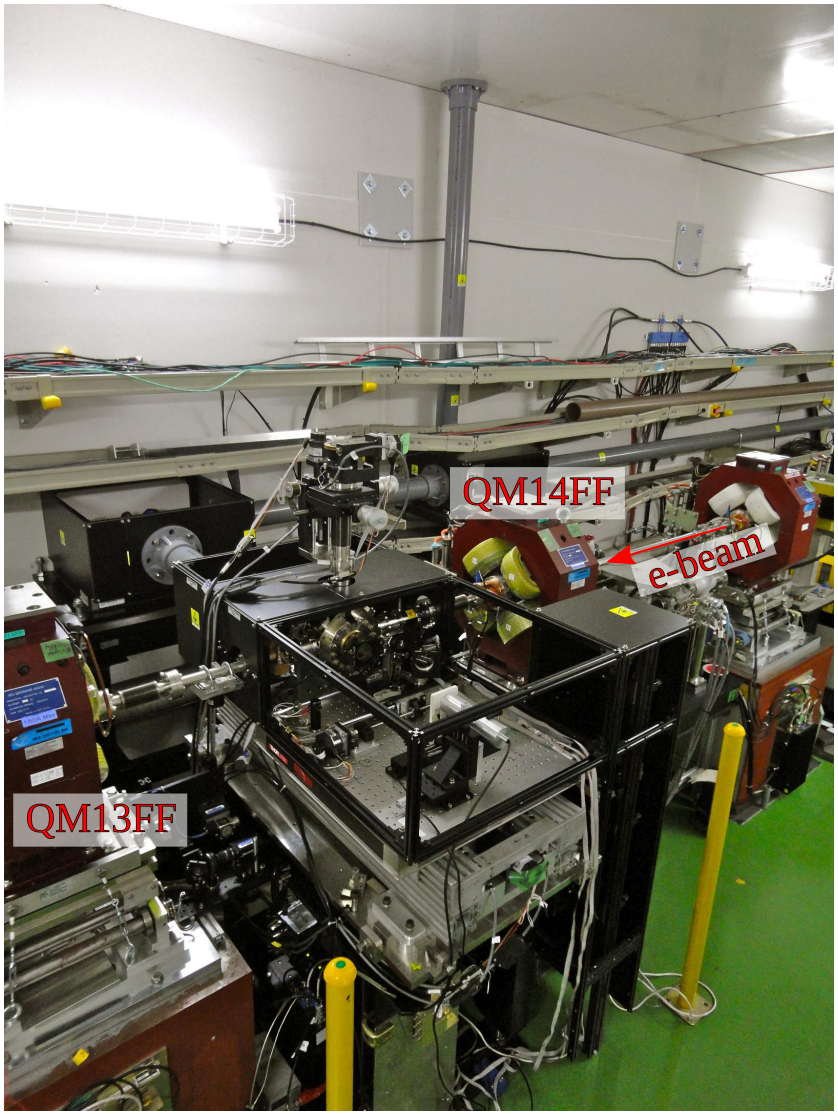
- Introduction
- Experimental setup
- Data analysis and calibration
- Monitor tuning
- Future improvements
- Summary

Introduction

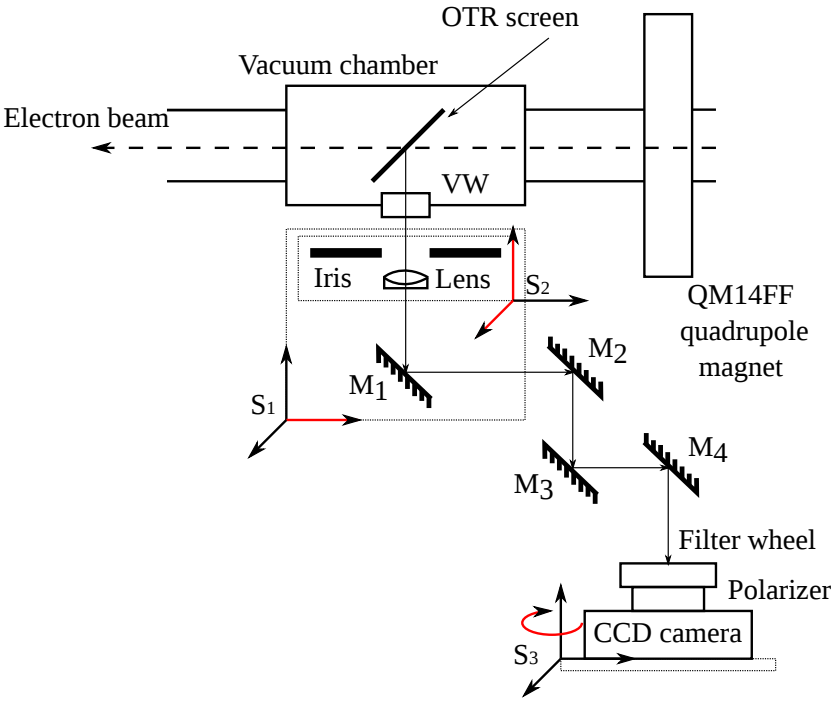


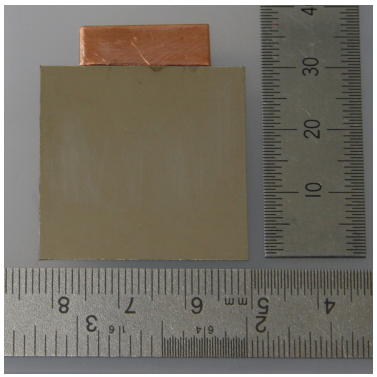
- Transition radiation (TR) appears when a charged particle crosses a boundary between two media with different dielectric constants.
- The resolution is determined by the source dimensions induced by a single particle plus distortion caused by the optical system (diffraction of OTR tails)

ATF II Extraction Line

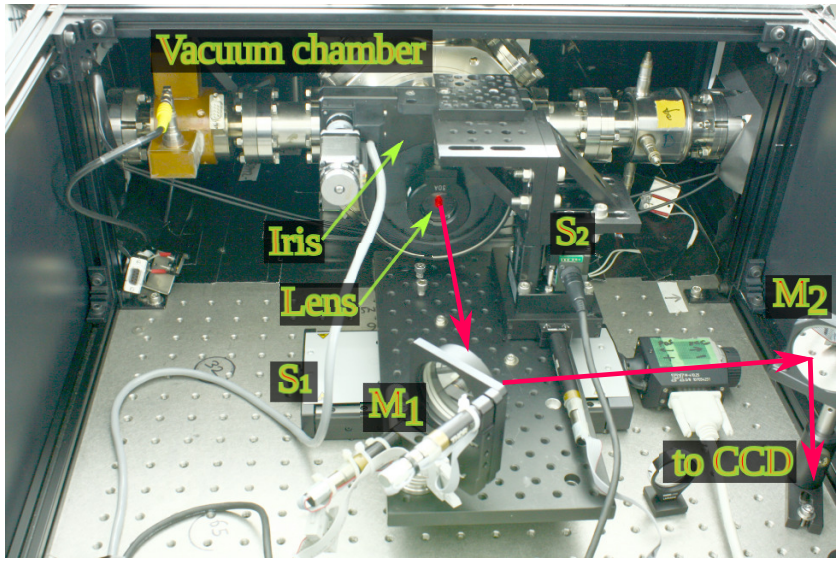


Experimental Setup





OTR screen



- Lens - "CVI Laser Optics" cemented achromat, f=120mm, ø=30mm
- CCD Camera - SBIG-ST8300M with 5.4 μm pixel size, 3352×2532 pixel array and ∼50% quantum efficiency

OTR Image

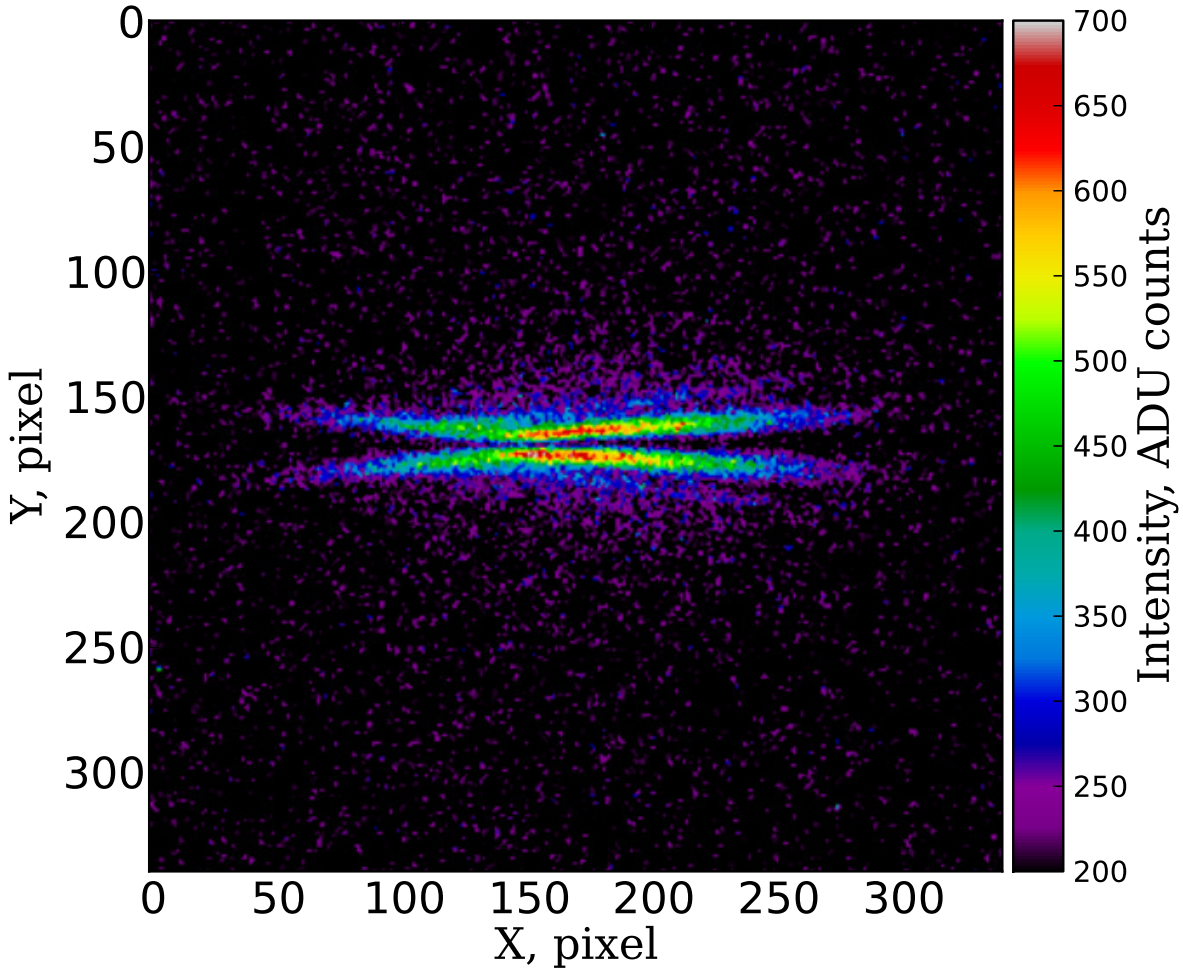
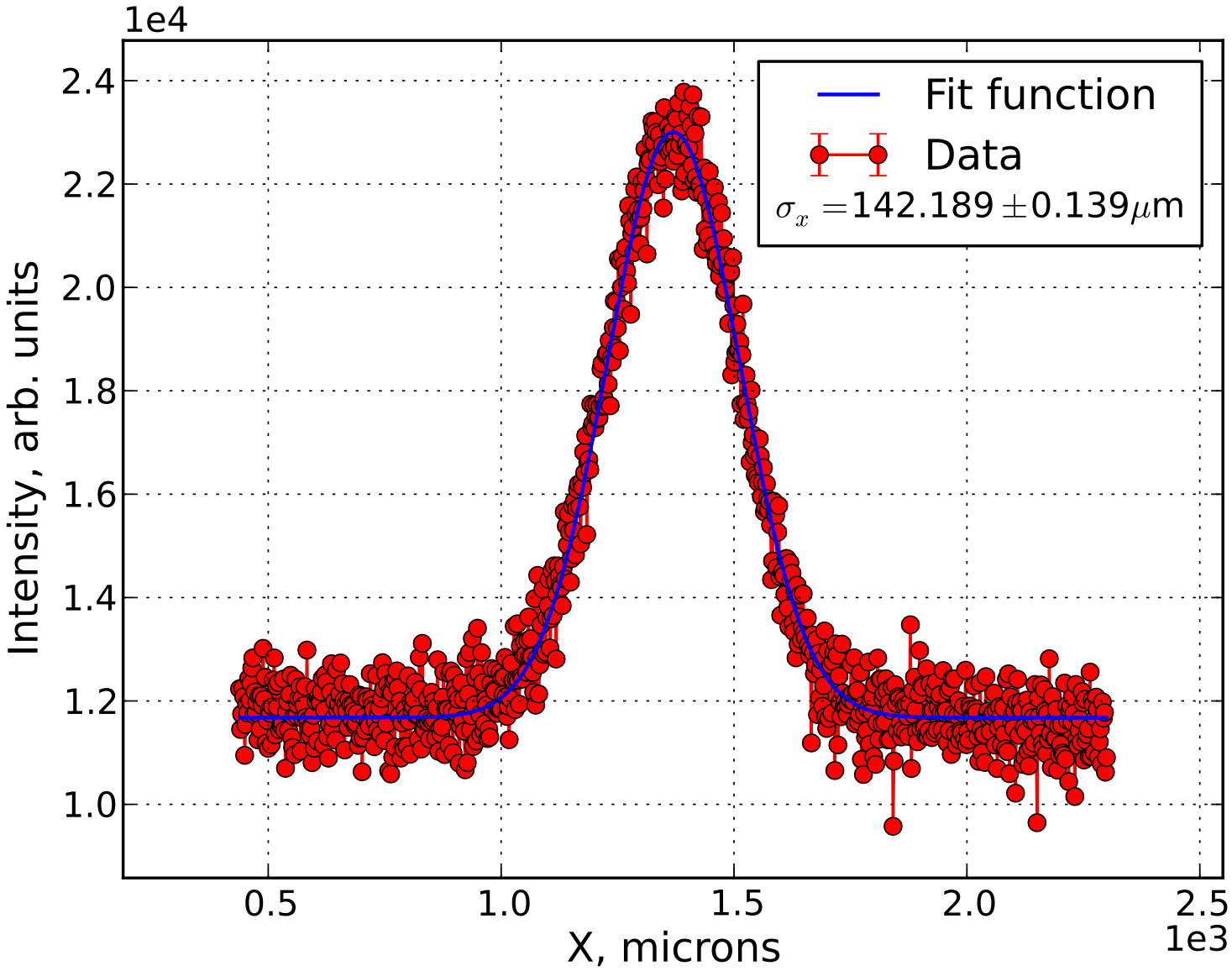
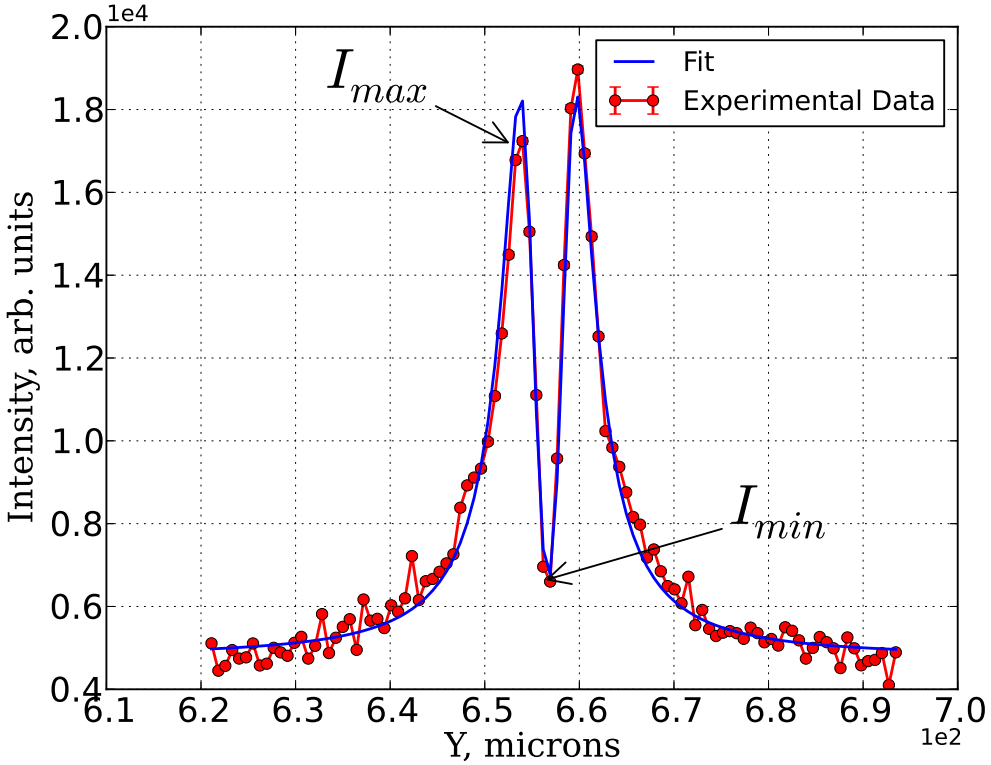


Image of the OTR spot taken with linear polarizer and 550±20 nm optical filter

Horizontal Projection



Vertical Projection



PSF-like fit function:

$$f(x) = a_0 + \frac{a_1\left(a_4 + (x - a_3)^2\right)}{1 + \left(a_2\left(x - a_3\right)\right)^4}$$

Fit parameters:

- a_0 is the vertical offset of the distribution with respect to zero
- a_1 is the amplitude of the distribution
- a_2 is the smoothing parameter
- a_3 is the horizontal offset of the distribution with respect to zero
- a_4 is the distribution width

PSF-like Fit Function

Analytical calculation of:

- Minimum to maximum ratio

$$I_{min}/I_{max} = \frac{2a_2^2 a_4}{2a_2^2 a_4 + \sqrt{1 + a_2^4 a_2^2}}$$

- Distance between peaks

$$\frac{2\sqrt{-a_2^2 a_4 + \sqrt{1 + a_2^4 a_2^2}}}{a_2}$$

- Simpler expressions for error calculation

Self Calibration Procedure

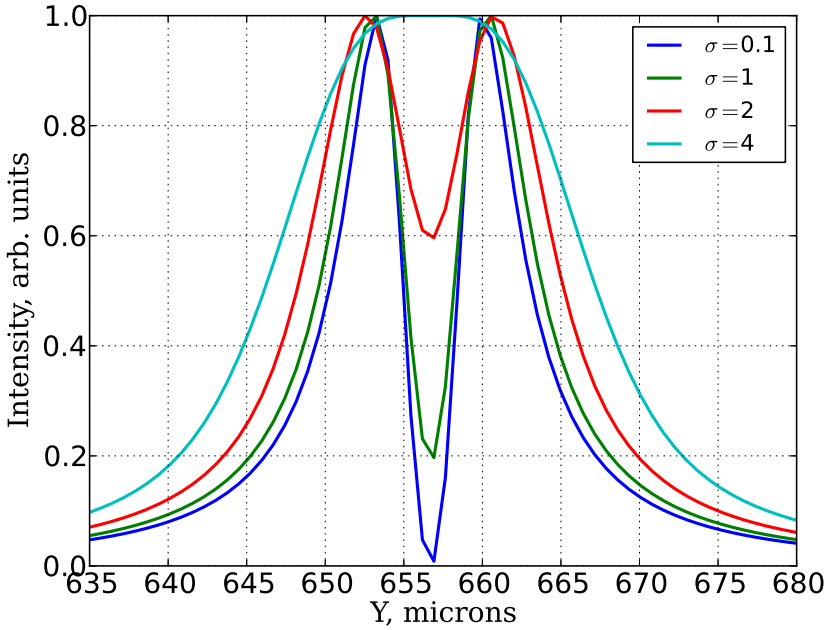
- In the whole data set find a file with smallest I_{min}/I_{max}
- Regenerate fit curve $f(x)$ with errors for the calibration file substituting zeros for horizontal offset a_0 and smoothing parameter a_4
- Convolute fit with Gaussian distribution as follows:

$$F(x_j) = \frac{\sum_{i=1}^{N} f(x_i) \exp\left(-\frac{(x_j - x_i)^2}{2\sigma^2}\right)}{\sum_{i=1}^{N} \exp\left(-\frac{(x_j - x_i)^2}{2\sigma^2}\right)}$$

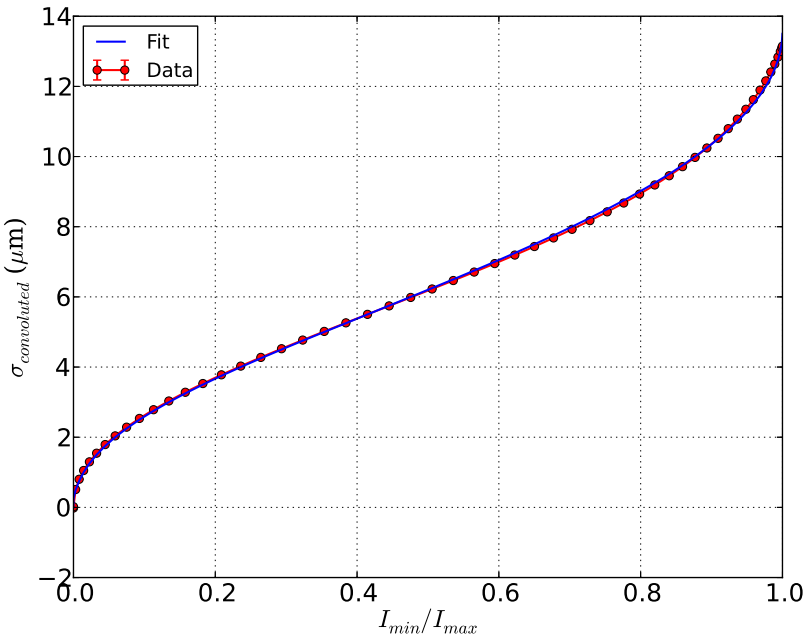
- Propagate errors through convolution.
- Repeat convolution N times varying σ from 0 to σ_m with a fine step.
- For each iteration. find I_{min}/I_{max} and calculate its errors resulting in calibration curve

Self Calibration Procedure

Beam size effect



Calibration curve

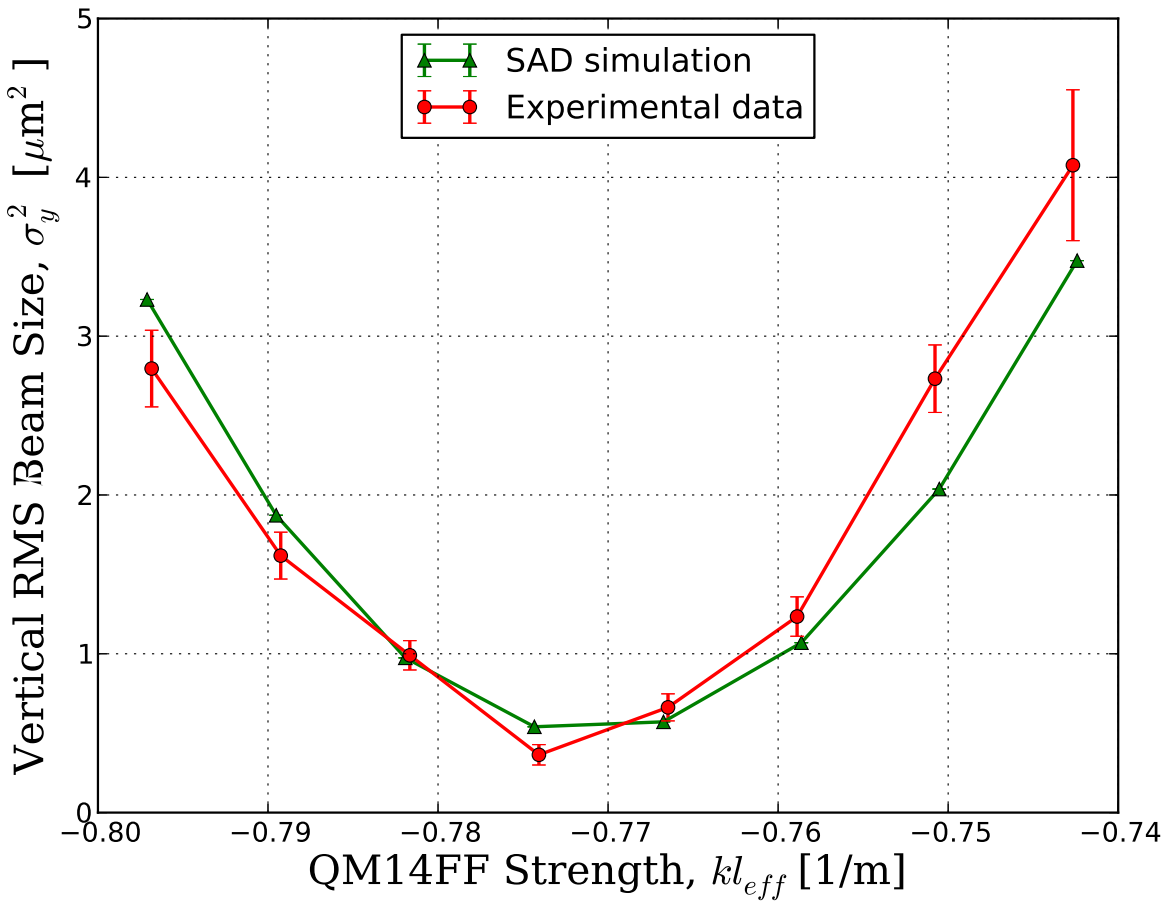


Fit function:

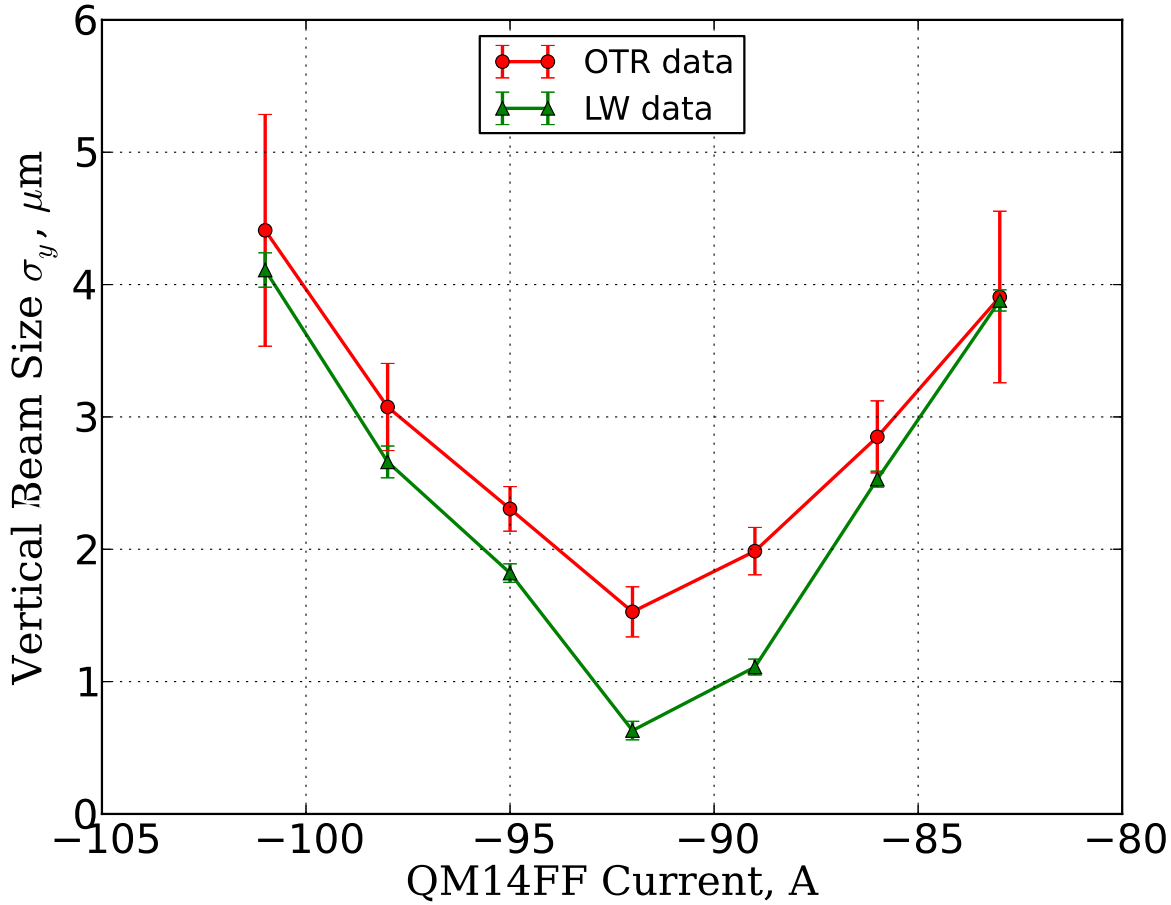
$$f(x) = a_0 + \frac{1}{a_1}\left(-\ln\left(1 - \frac{x}{a_2}\right)\right)^{a_3} + a_4 x^{12}$$

Best Quadrupole Scan

Minimum measured beam size was: 0.754±0.034 μm



LW and OTR Comparison



More about LW see at MOPF16

Monitor Tuning and Optimization

Off - line:

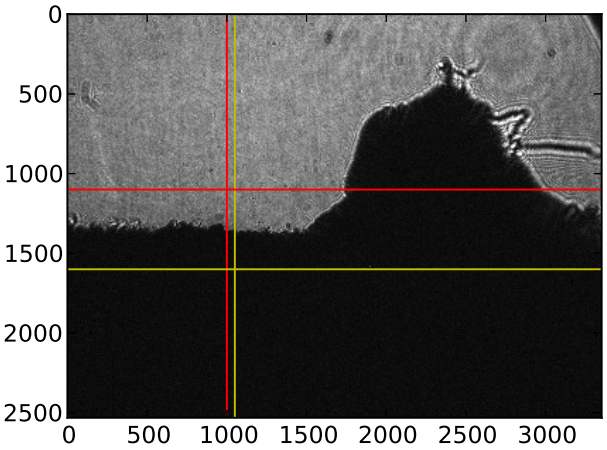
- Alignment of the optical system and magnification factor measurements

On - line:

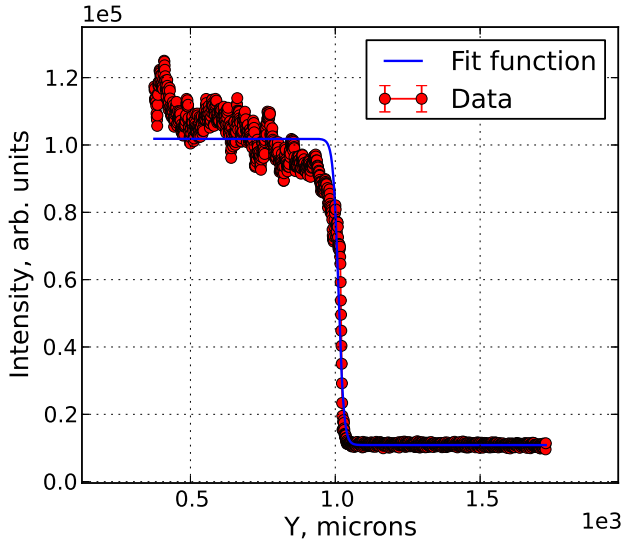
- Find OTR spot
- Optimization
  - Polarizer angle
  - Focusing scan
  - Image rotation scan
- Quadrupole scan
  - Find a file with the best visibility and perform calibration

Calibration of The Optical System

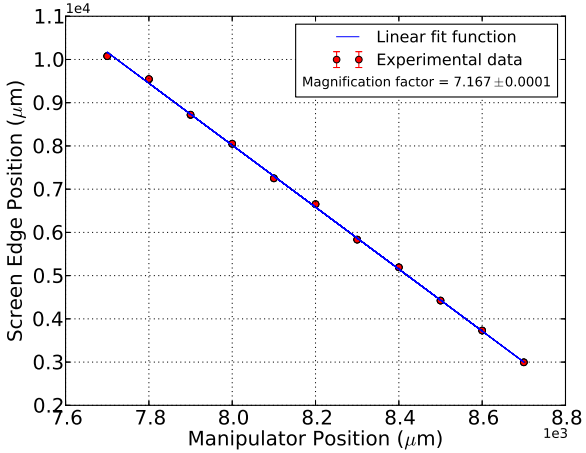
Image of the OTR screen



Vertical projection



Calibration curve

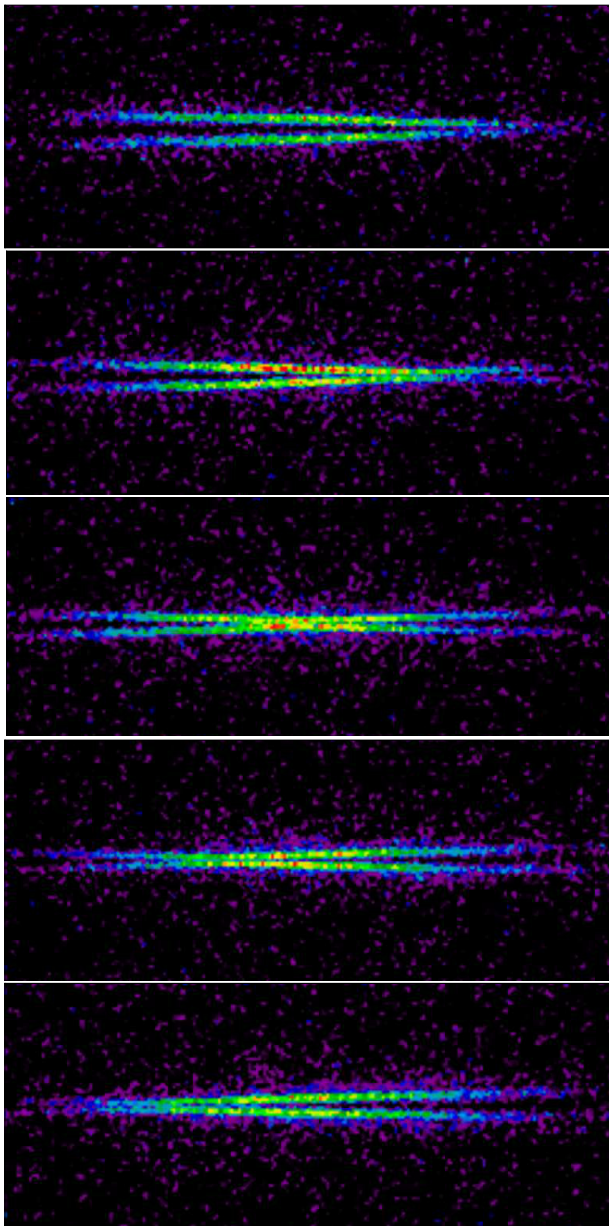


Fit function:

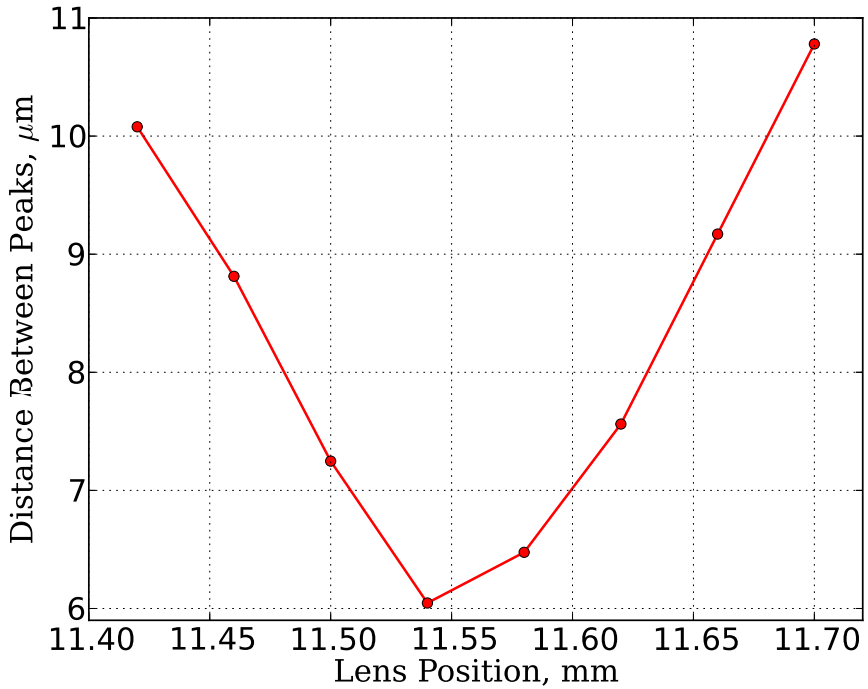
$$f(x) = a_0 + \frac{a_1}{1 + \exp\left(\frac{x - a_3}{a_2}\right)}$$

Measured magnification factor of the system: 7.17

Focusing

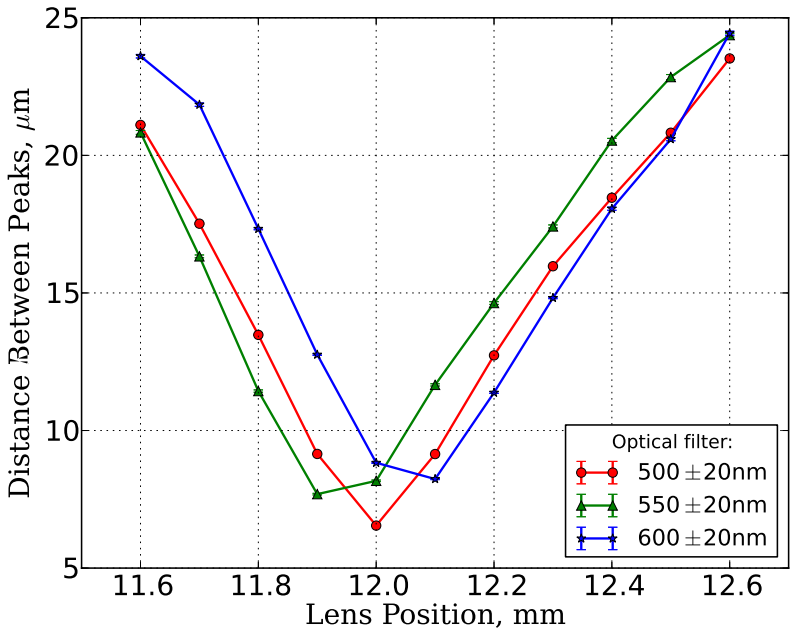


Focus-scan:

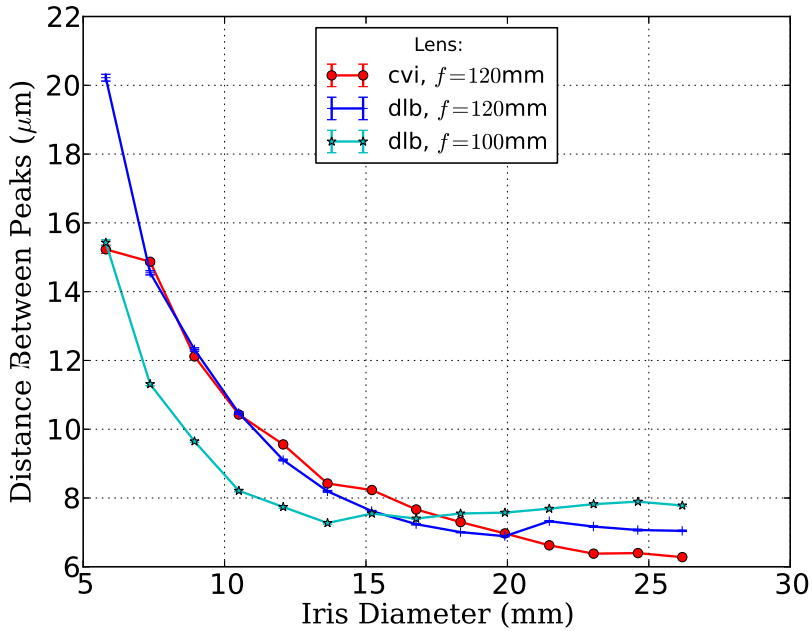


Optical Effects Study

Chromatic aberrations



Diffraction



Lens	Properties
"Sigma Koki" achromatic doublets:	
DLB-30-120-PM	f=120 mm, ø=30 mm
DLB-30-100-PM	f=100 mm, ø=30 mm
"CVI Laser Optics" achromat lens	
CVI LAO-120-30	f=120 mm, ø=30 mm
"Sigma Koki" plano-convex lens:	
SLB-30-100-PM	f=100 mm, ø=30 mm

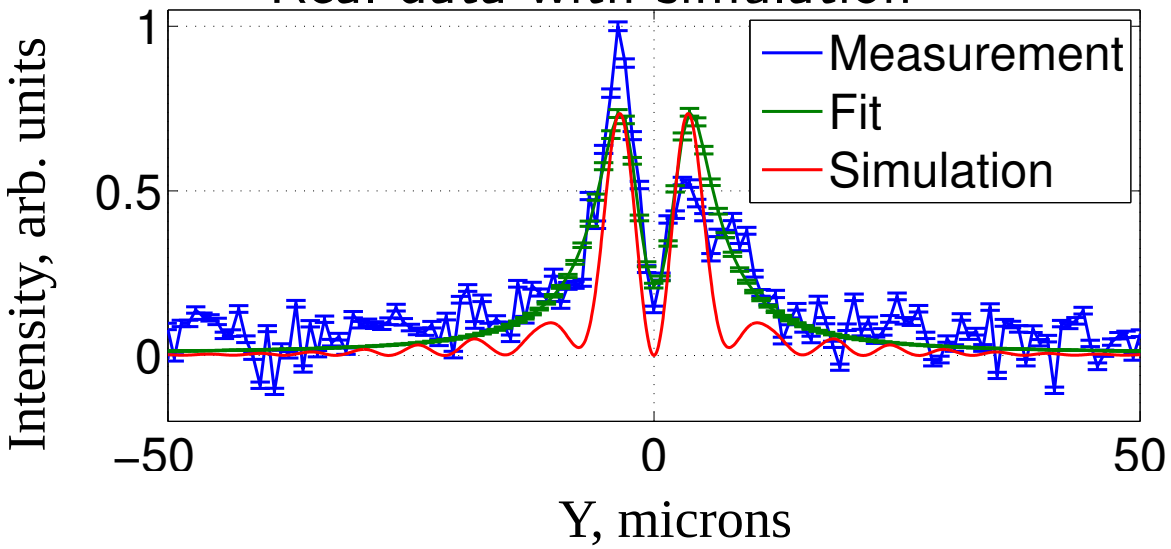
Future Improvements

- Using simulation tools such as ZEMAX in order to better understand the PSF behavior and optimize the optical system (see MOPF04)
- Apply multi-element or reflective optics in order to reduce the resolution even further
- Upgrade experimental hardware (CCD camera, DAQ)
- Efforts towards automation (shot by shot beam size measurements)

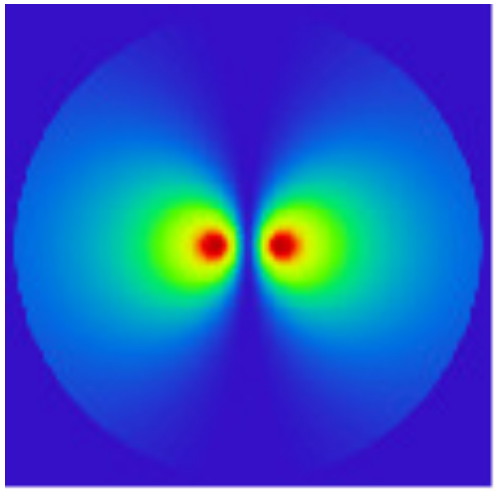
ZEMAX Simulations (MOPF04)

- Zemax "Physical Optics Propagation" simulations: Propagation of the OTR source using diffraction laws (near field conditions) through real commercial lenses
- PSF simulation: Propagation of vertically polarized electric field for a single electron

Real data with simulation



Simulated 3D OTR distribution



Summary

- Collected Data shows a good progress in optimization of PSF-like OTR monitor system
- 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.
- Work on analysis and simulations shows good agreement with experimental data