

# Sub-micrometer Transverse Beam Size Diagnostics Using Optical Transition Radiation

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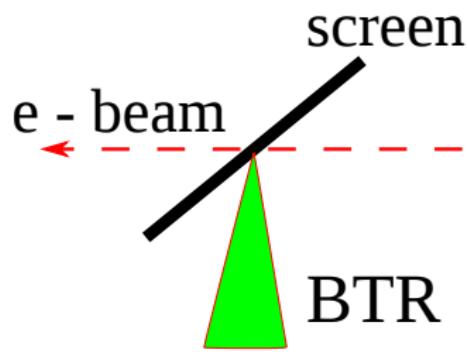
CERN, Geneva, Switzerland



# Outlines

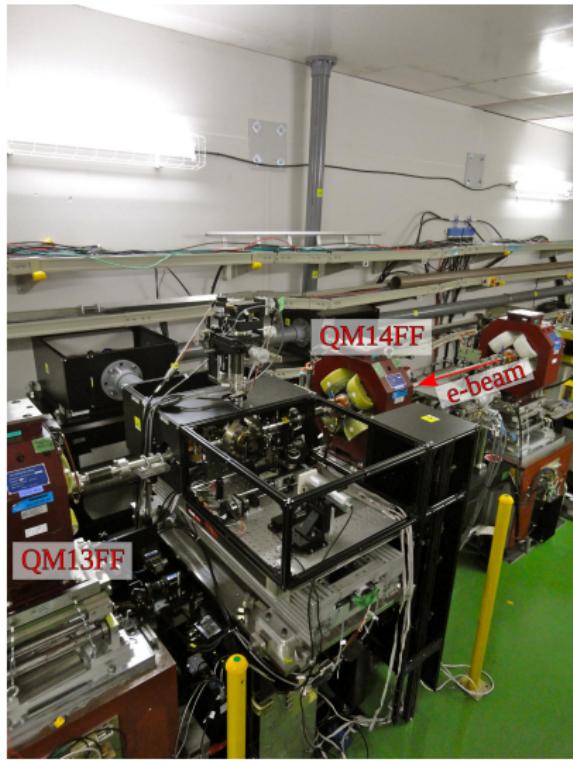
- Introduction
- Experimental setup
- Data analysis and calibration
- Monitor tuning
- Future improvements
- Summary

# Introduction

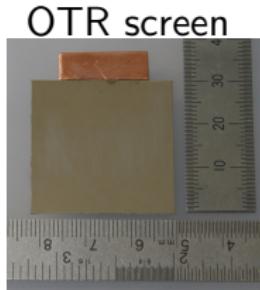
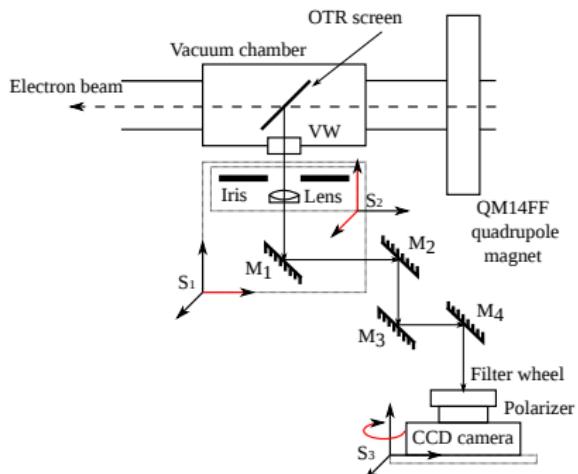


- Transition radiation (TR) appears when a charged particle crosses a boundary between two media with different dielectric constants.
- The resolution is determined by the source dimensions induced by a single particle plus distortion caused by the optical system (diffraction of OTR tails)

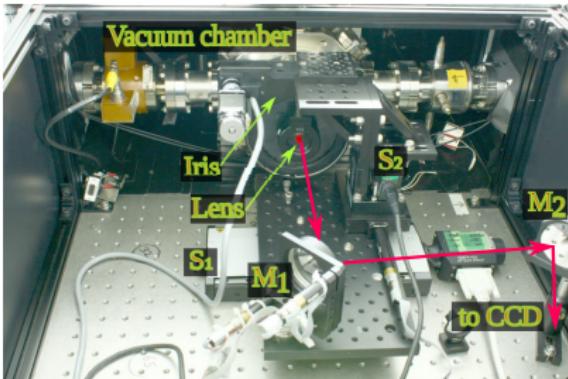
# ATF II Extraction Line



# Experimental Setup



0.3×30×30 mm aluminized silicon



- Lens - "CVI Laser Optics" cemented achromat,  $f=120\text{mm}$ ,  $\phi=30\text{mm}$
- CCD Camera - SBIG-ST8300M with  $5.4 \mu\text{m}$  pixel size,  $3352\times2532$  pixel array and  $\sim 50\%$  quantum efficiency

# OTR Image

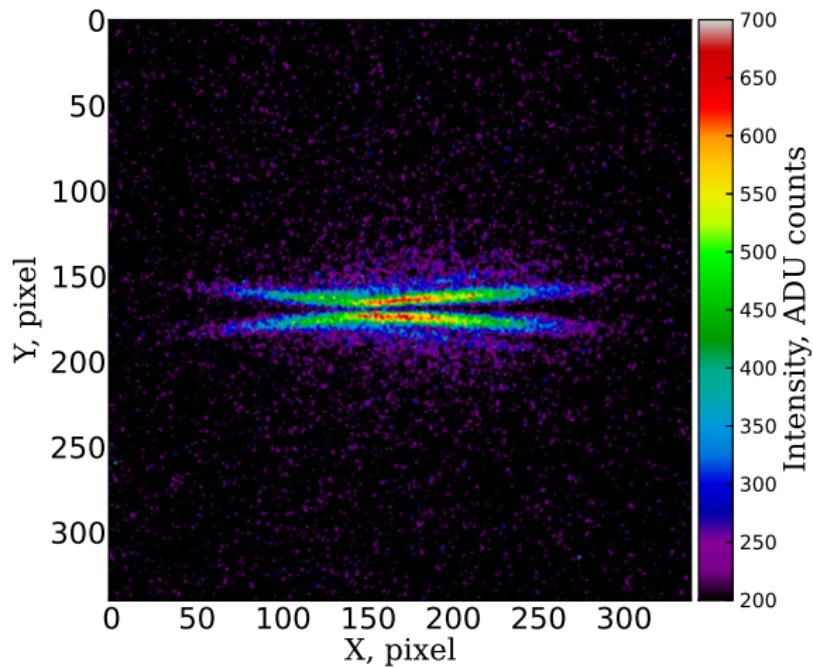
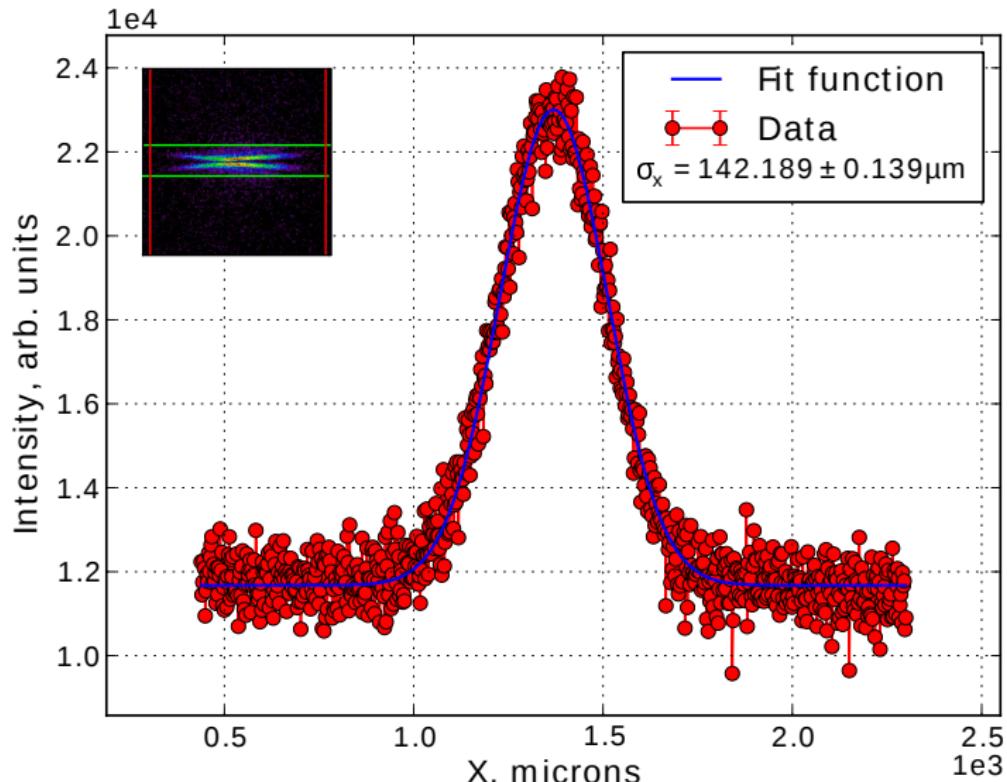
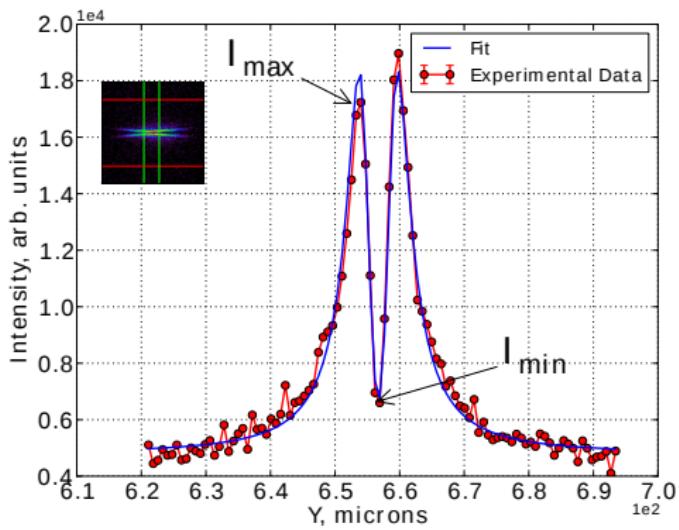


Image of the OTR spot taken with linear polarizer and  $550 \pm 20$  nm optical filter

# Horizontal Projection



# Vertical Projection



PSF-like fit function:

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

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

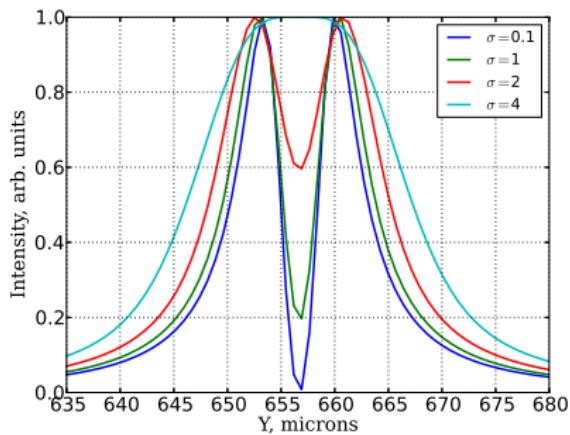
- In the whole data set find a file with smallest  $I_{min}/I_{max}$
- Regenerate fit curve  $f(x)$  with errors for the calibration file substituting zeros for vertical offset  $a_0$  and smoothing parameter  $a_4$
- Convolute fit with Gaussian distribution as follows:

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

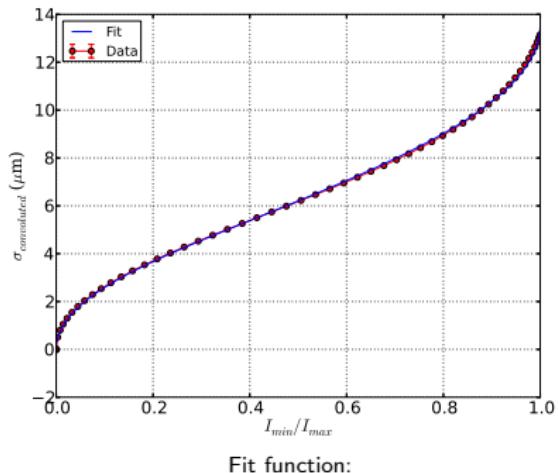
- Propagate errors through convolution.
- Repeat convolution N times varying  $\sigma$  from 0 to  $\sigma_m$  with a fine step.
- For each iteration. find  $I_{min}/I_{max}$  and calculate its errors resulting in calibration curve

# Self Calibration Procedure

Beam size effect



Calibration curve

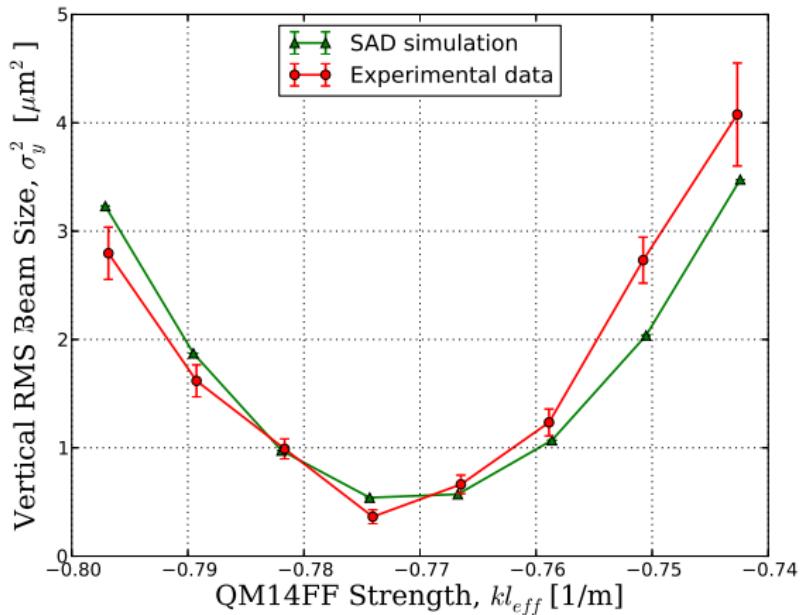


Fit function:

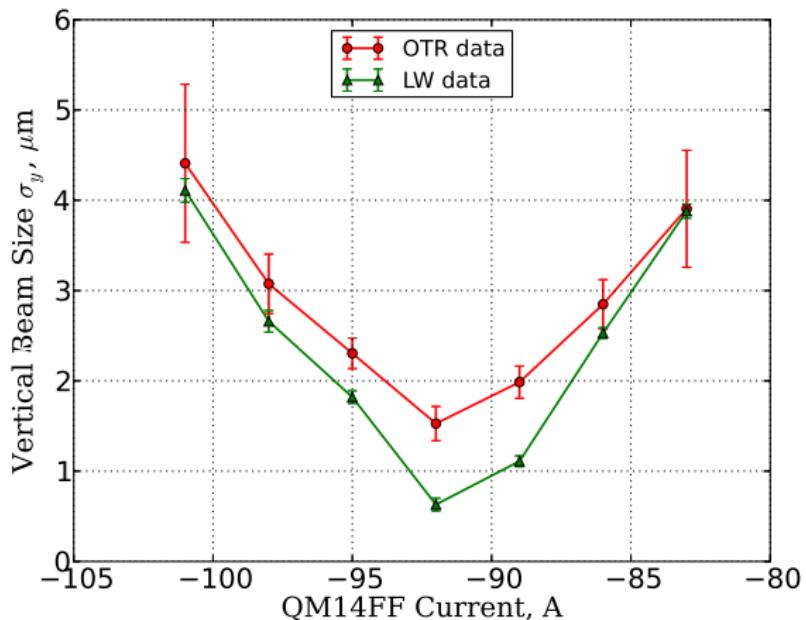
$$f(x) = a_0 + \frac{1}{a_1} \left( -\ln \left( 1 - \frac{x}{a_2} \right) \right)^{a_3} + a_4 x^{12}$$

# Best Quadrupole Scan

Minimum measured beam size was:  $0.754 \pm 0.034 \mu\text{m}$



# LW and OTR Comparison



More about LW see at [Proceedings of IBIC13, MOPF16](#)

# Monitor Tuning and Optimization

Off - line:

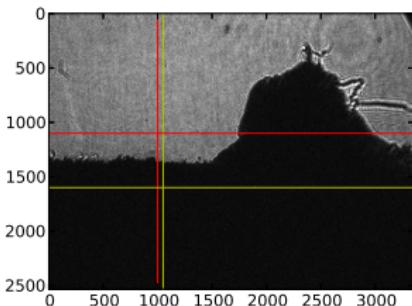
- Alignment of the optical system and magnification factor measurements

On - line:

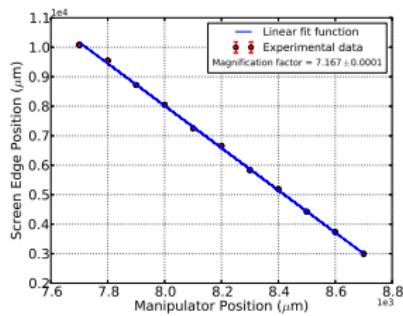
- Find OTR spot
- Optimization
  - Polarizer angle
  - Focusing scan
  - Image rotation scan
- Quadrupole scan
  - Find a file with the best visibility and perform calibration

# Calibration of The Optical System

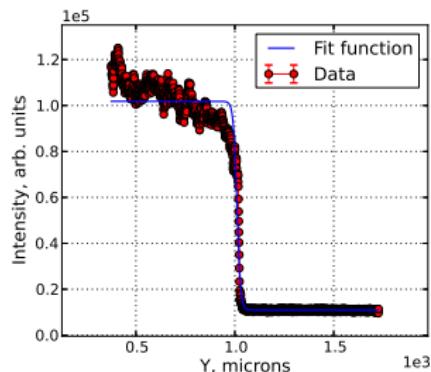
Image of the OTR screen



Calibration curve



Vertical projection

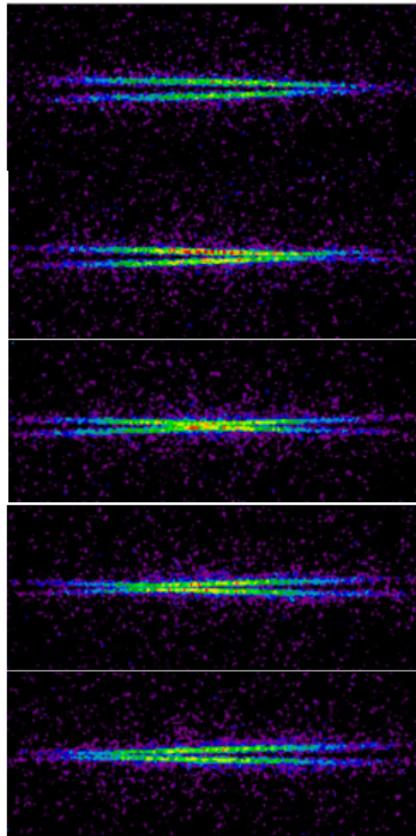


Fit function:

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

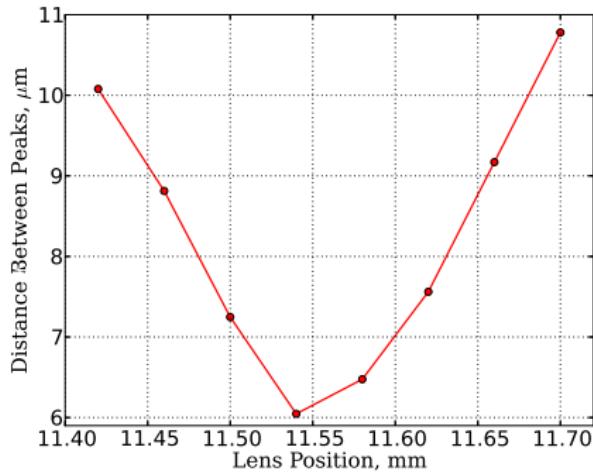
Measured magnification factor of  
the system: 7.17

# Focusing



11.70 mm    11.32 mm    11.54 mm    11.42 mm    11.30 mm

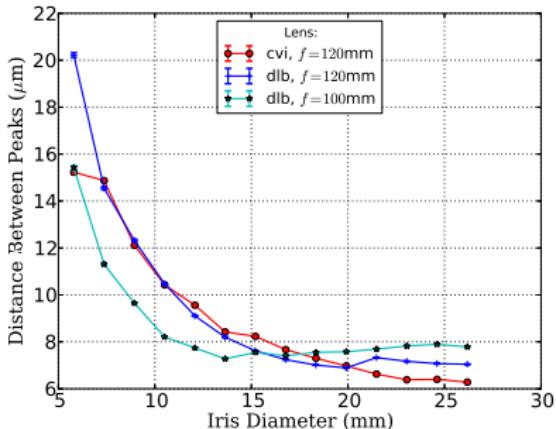
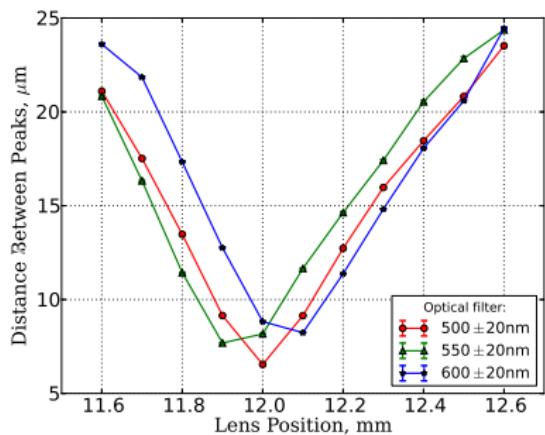
Focus-scan:



# Optical Effects Study

## Diffraction

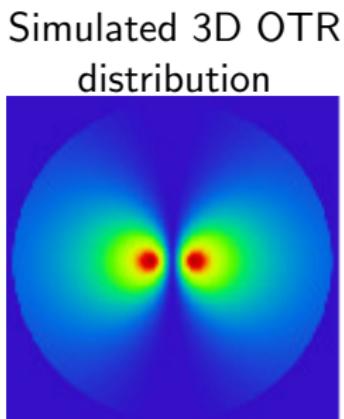
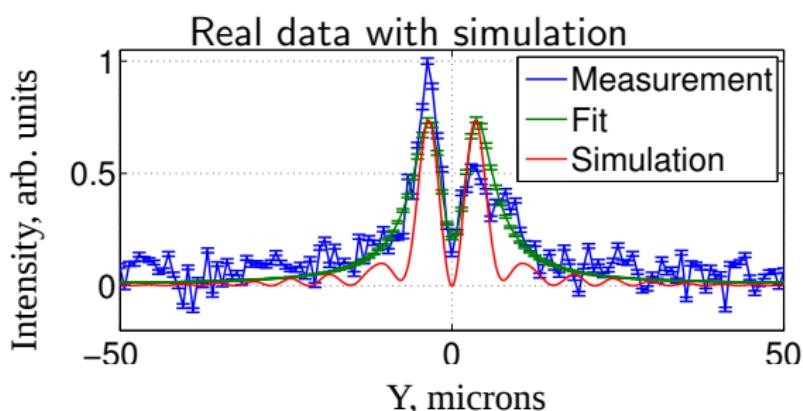
### Chromatic aberrations



Lens	Properties
"Sigma Koki" achromatic doublets:	
DLB-30-120-PM	$f=120 \text{ mm}, \phi=30 \text{ mm}$
DLB-30-100-PM	$f=100 \text{ mm}, \phi=30 \text{ mm}$
"CVI Laser Optics" achromat lens	
CVI LAO-120-30	$f=120 \text{ mm}, \phi=30 \text{ mm}$
"Sigma Koki" plano-convex lens:	
SLB-30-100-PM	$f=100 \text{ mm}, \phi=30 \text{ mm}$

# ZEMAX Simulations

- 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



\*Proceedings of IBIC13, MOPF04

## Future Improvements

- Using simulation tools such as ZEMAX in order to better understand the PSF behavior and optimize the optical system
- 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)

# 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