THEORETICAL AND EXPERIMENTAL INVESTIGATION ON RESOLUTION OF OPTICAL TRANSITION RADIATION TRANSVERSE BEAM PROFILE MONITOR.

A. Aryshev, N. Terunuma, J. Urakawa
KEK ATF
S. Boogert, P. Karataev, L. Nevay
JAI at RHUL
T. Lefevre, E. Bravin, B. Bolzon
CERN CTF3

alar@post.kek.jp

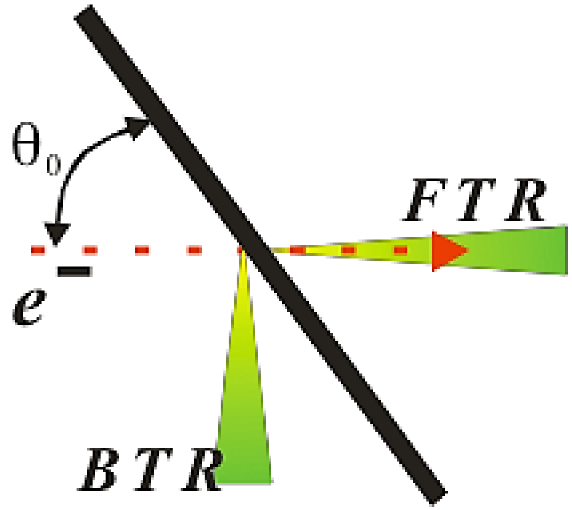
Outline

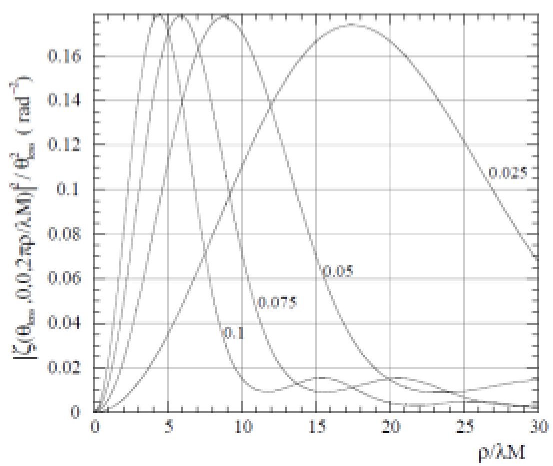
- Introduction and overview
- High resolution OTR: basic concept
- ATF OTR project milestones
- Setup overview
- Data analysis and calibration
- Monitor tuning and optimization
- Future improvements and prospects
- Summary

Introduction

ATF web: http://atf.kek.jp/

OTR single particle image

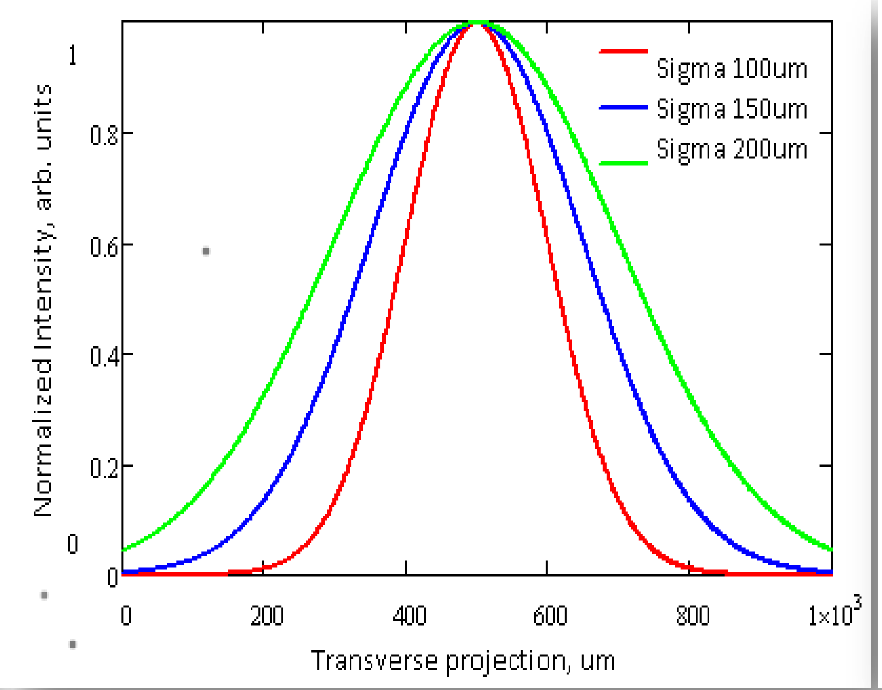




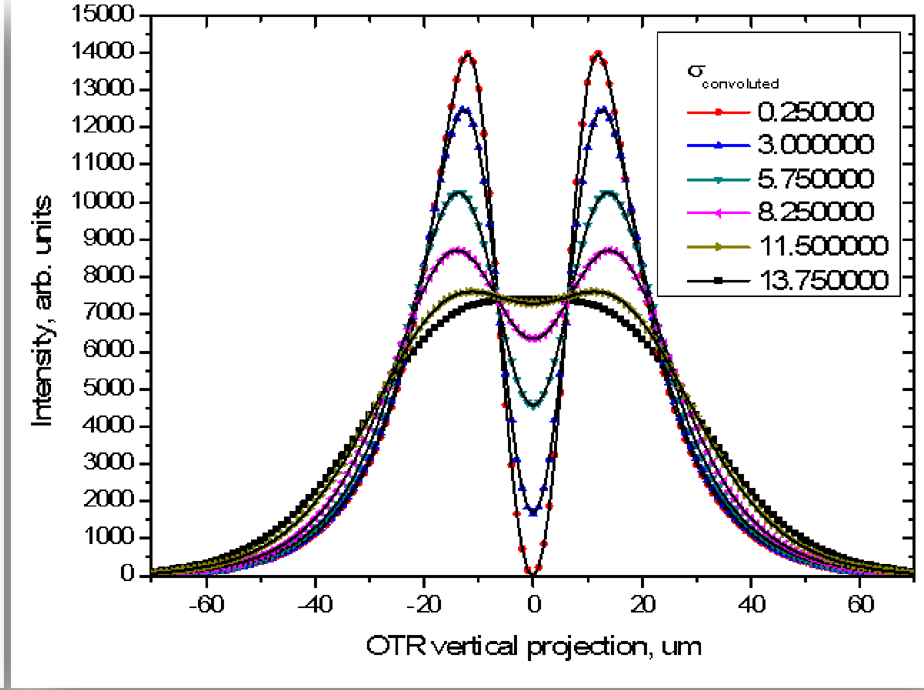
- Transition radiation (TR) appears when a charged particle crosses a boundary between two media with different dielectric constants.
- The resolution is determined by the source dimensions induced by a single particle plus distortion caused by the optical system (diffraction of OTR tails)
- M. Castellano and V. A. Verzilov, PRST-AB **1**, 062801 (1998)
- P. Karataev et al. NIMB 227 (2005) 198–208

Beam size effect on OTR

"Usual" OTR image



OTR vertical polarization component, for sigma < ~15 um

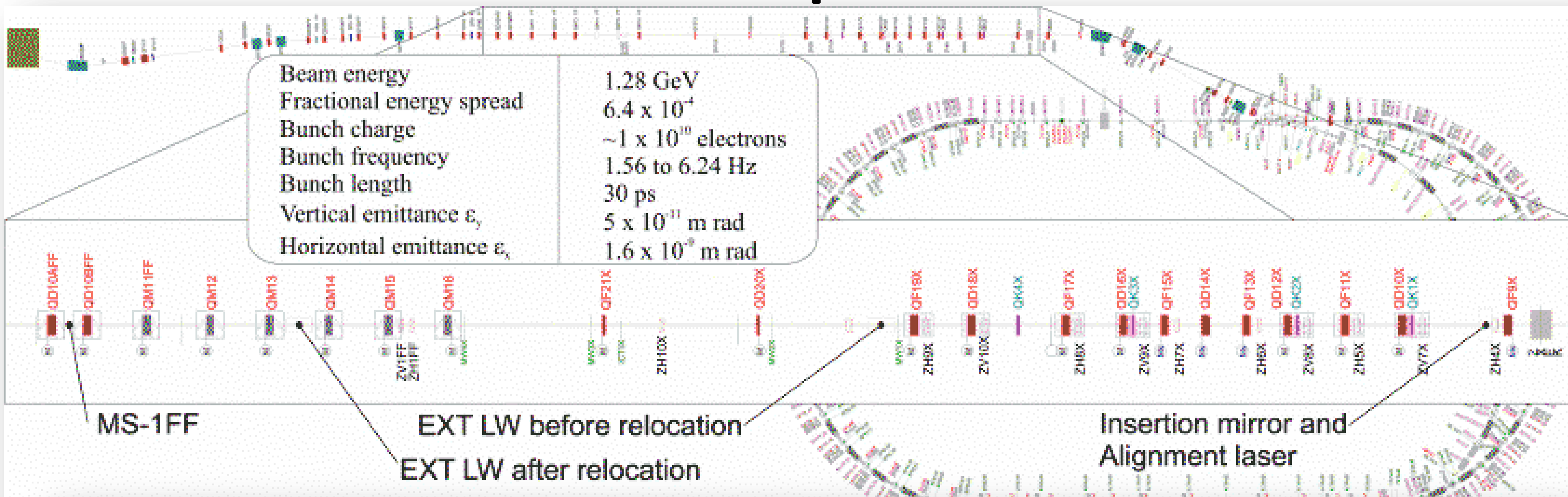


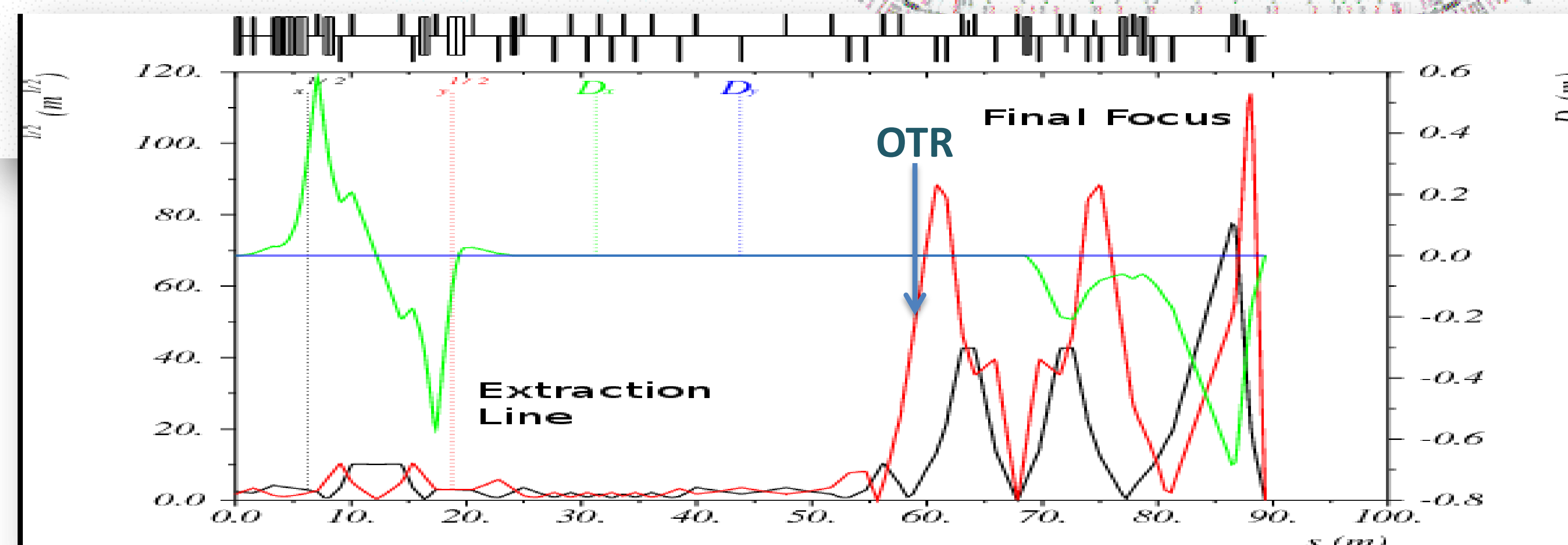
Milestones

- **Initial setup – spring 2009**
  - A.Aryshev, P. Karataev, et. al., Journal of Physics: Conference Series 236 (2010) 012008.
- **Observation of OTR PSF – end of 2009**
  - P. Karataev , A.Aryshev, et. al., PRL 107, 174801 (2011)
- **e-optics verification, monitor start-up end of 2009 – 2011**
  - A. Aryshev, P. Karataev, et. al., IPAC'10, Kyoto, Japan, MOPEA053
  - A. Aryshev, P. Karataev, et. al., IPAC'11, San-Sebastian, Spain,WEOBB01
  - A. Aryshev, P. Karataev, et. al., RREPS'11, 12 – 16 September 2011, Royal Holloway University of London, Egham, United Kingdom
- **Routine EXT LW cross-checking – from spring 2012**

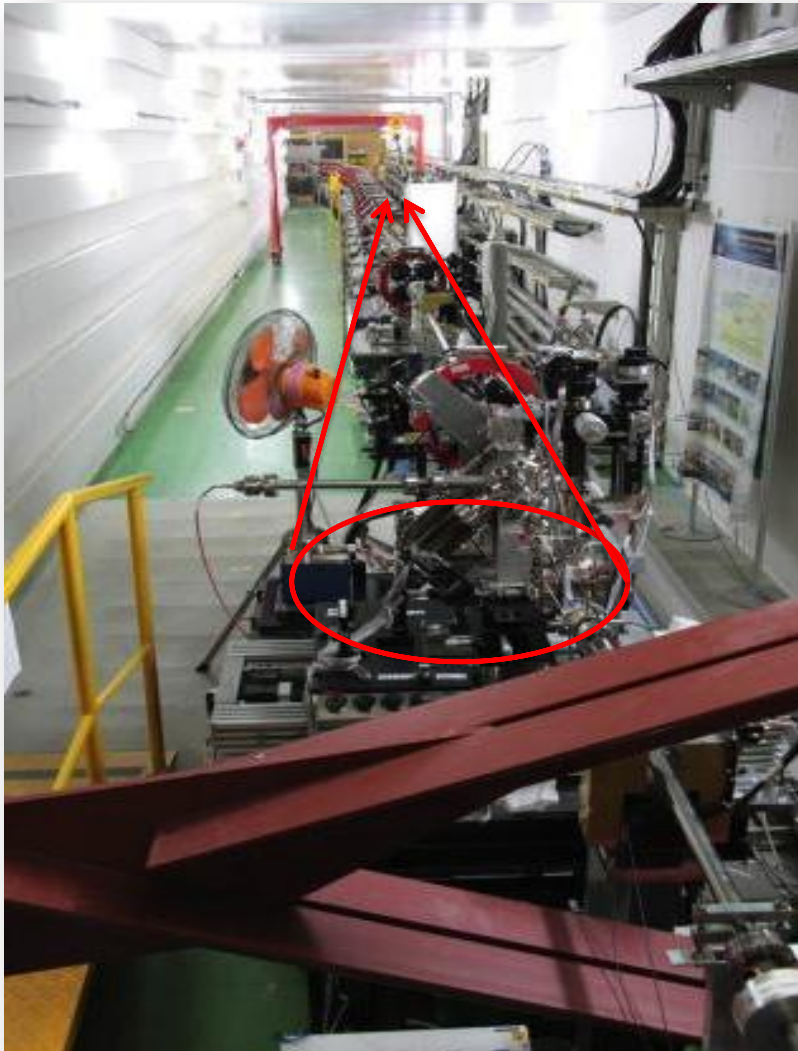
KEK ATF-II, beam parameters

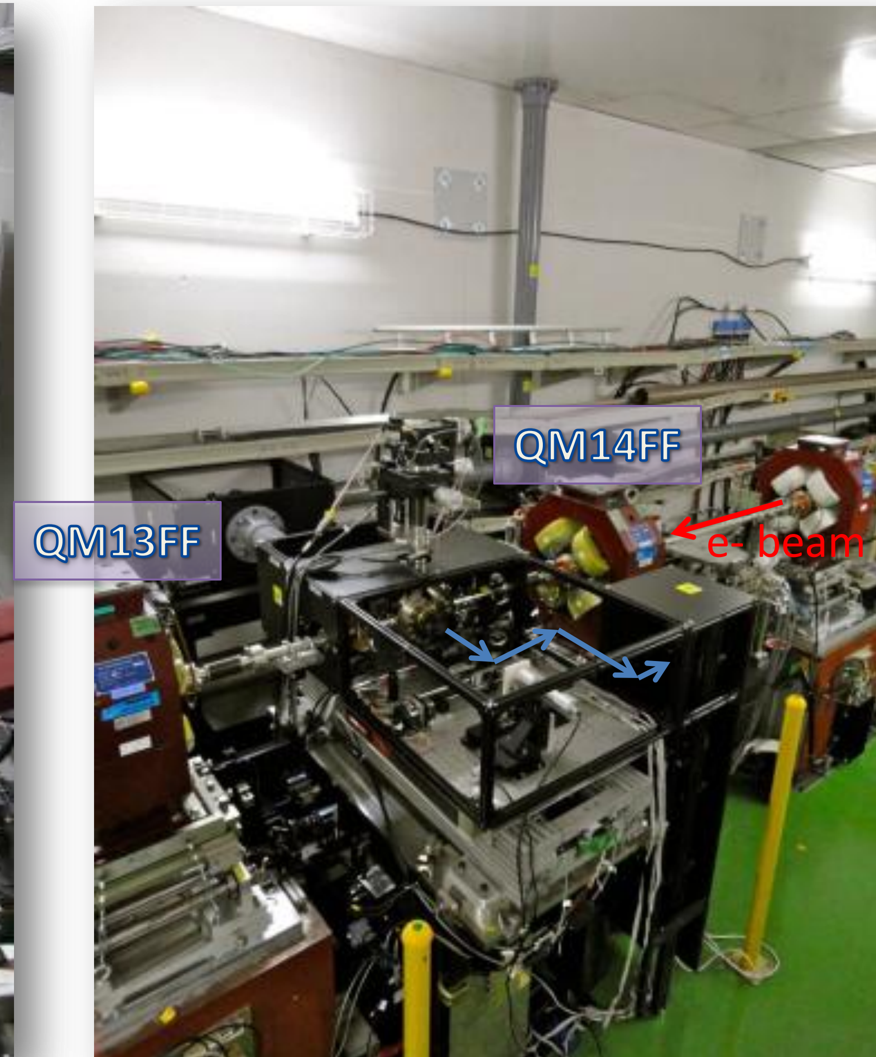
Beam energy	1.28 GeV
Fractional energy spread	6.4 x 10^{-4}
Bunch charge	~1 x 10^{10} electrons
Bunch frequency	1.56 to 6.24 Hz
Bunch length	30 ps
Vertical emittance ε_y	5 x 10^{-11} m rad
Horizontal emittance ε_x	1.6 x 10^{-9} m rad



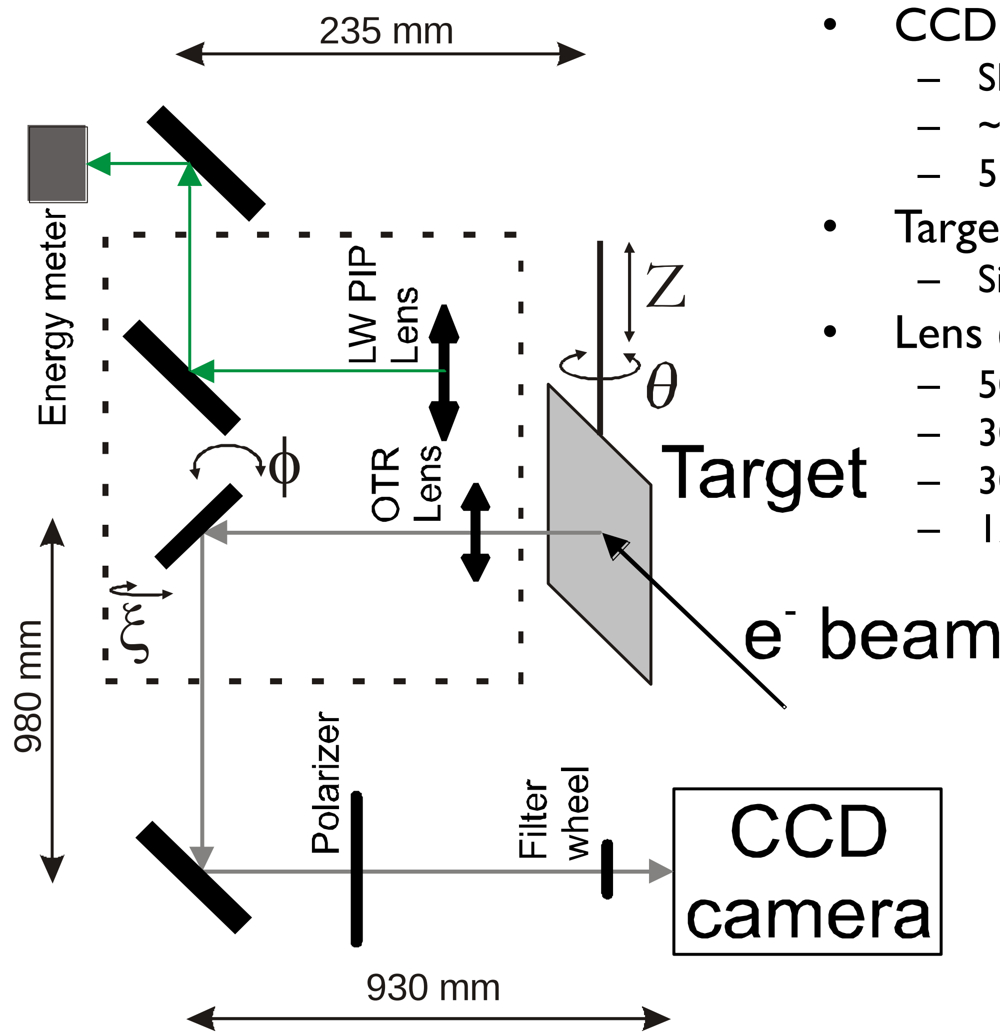


ATF-II beam line, OTR setup





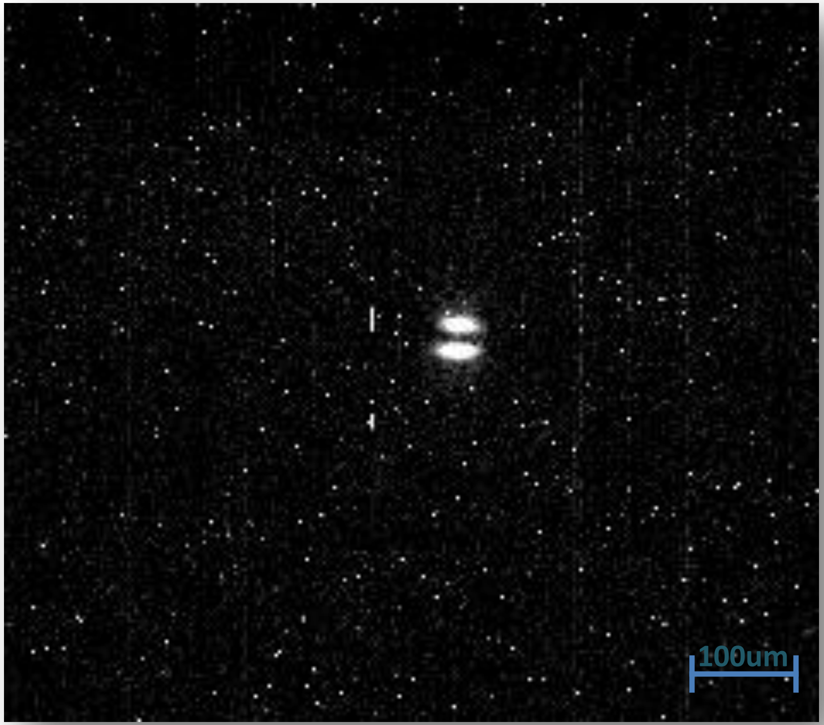
Setup overview



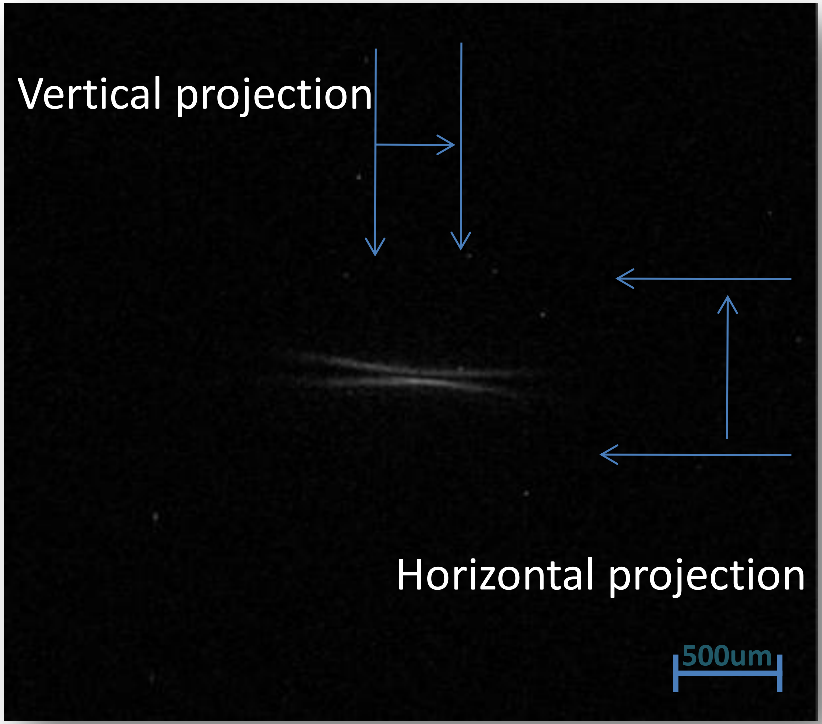
- CCD replacement:
  - SBIG ST 8300 MT
  - ~ 50% Q.E. @ 550nm
  - 5.4 um/pixel
- Target
  - Si wafer coated with Al, 30x30x0.3 mm
- Lens (tested since 2009)
  - 50mm f=120mm
  - 30mm f=120mm
  - 30mm f=120 achromat
  - 12.6mm f=100mm

OTR images

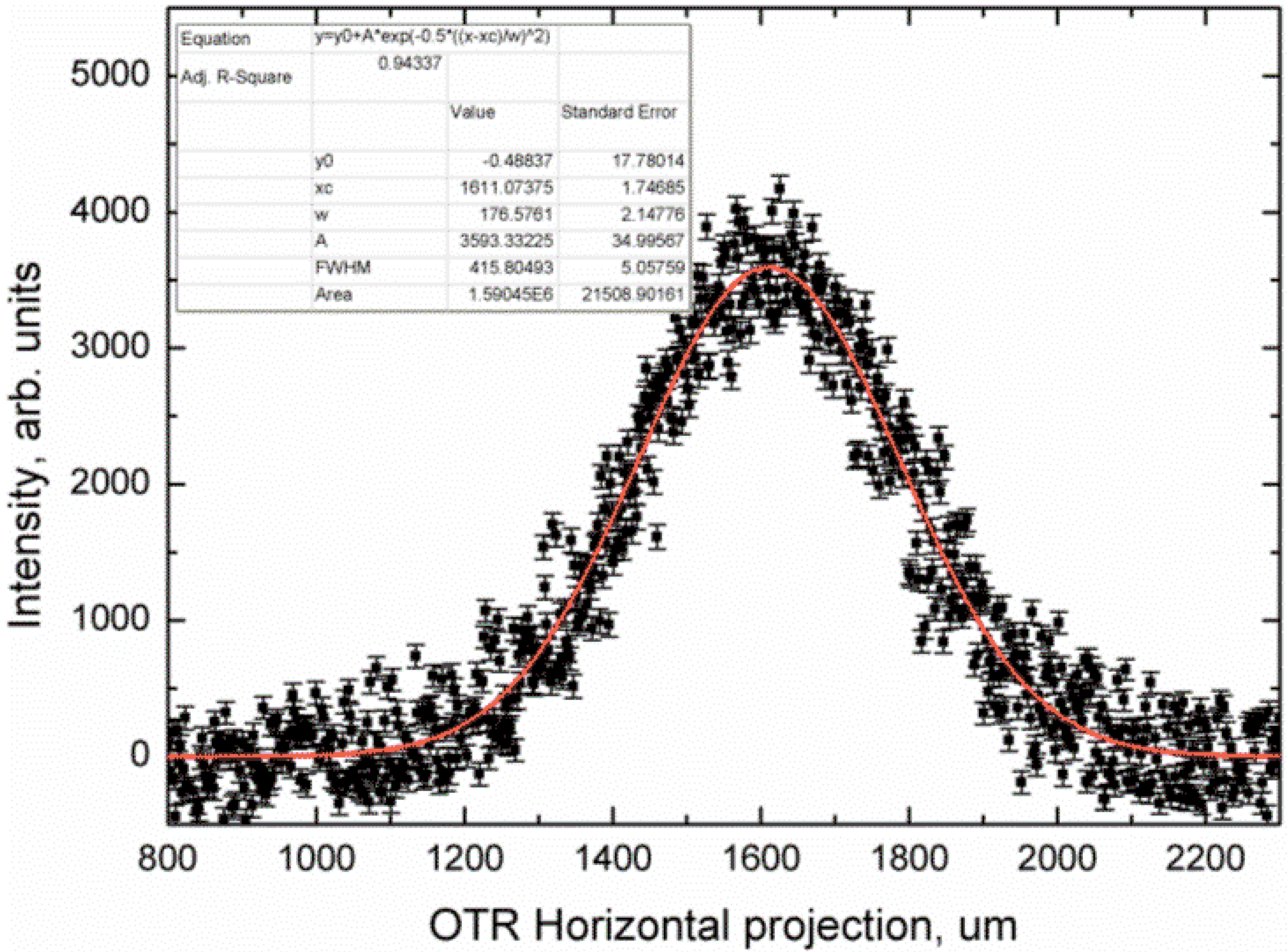
OTR image @ previous location



OTR image @ current location

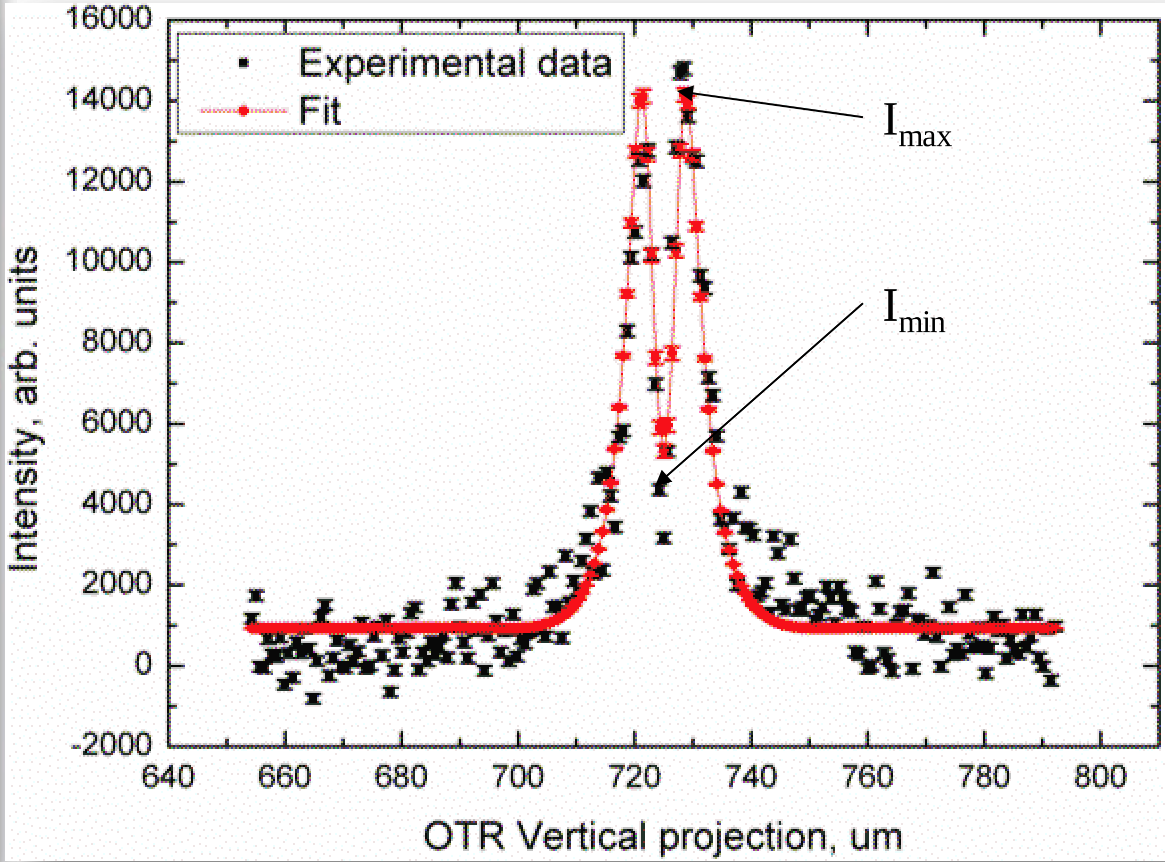


OTR, Horizontal projection



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	929.693 +/- 6.76
b	51015.2 +/- 161.58
c	0.232 +/- 0.00049
Δx	725.01 +/- 0.0066
σ	1.8295 +/- 0.014

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

What corresponds electron beam sire of **σ** = 1.66 **+/-** 0.52

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.

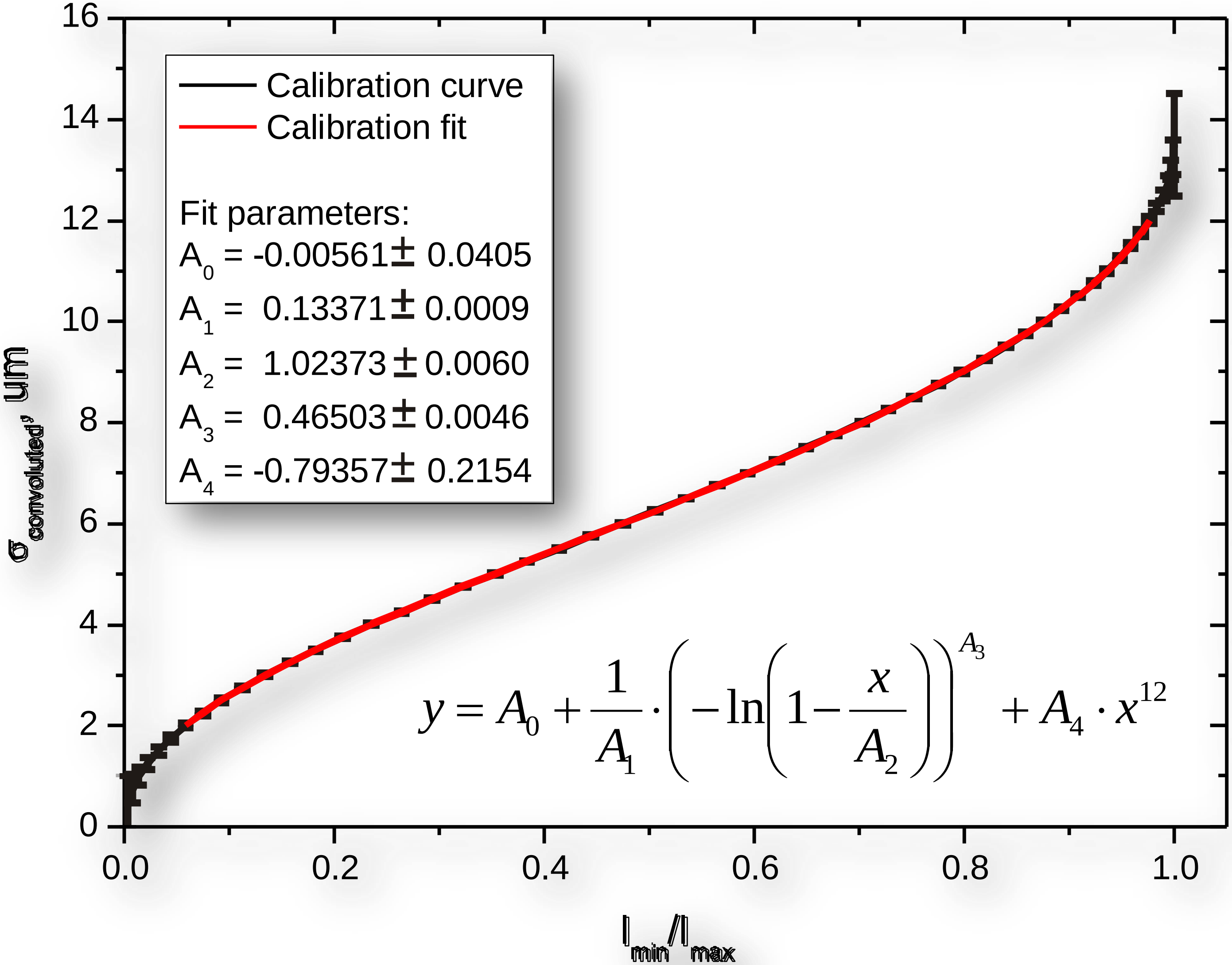
Self-Calibration procedure

- Convolute re-generated fit *f(x)* with Gaussian distribution 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 *Δf(x)* through convolution according to $\Delta f(x) = \sqrt{\sum (f(x)')_i^2 \cdot \Delta_i^2}$, 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.

Self-Calibration procedure



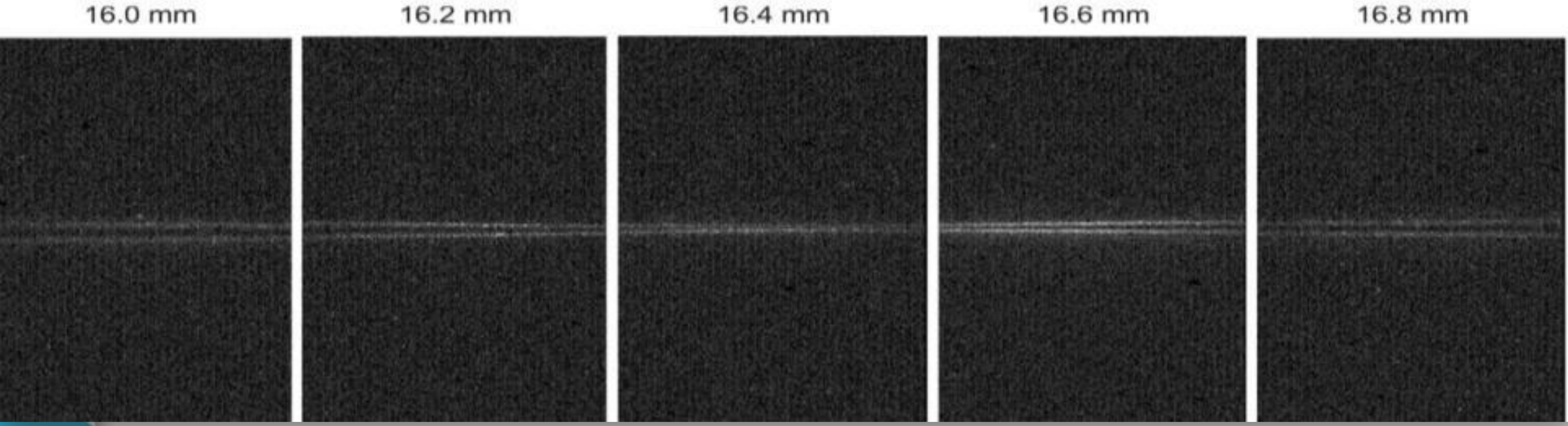
Self-Calibration procedure

- Propagate errors through calibration fit.
- Analyse 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.

Monitor tuning and optimization

- Input: optical line magnification factor, CCD pixel size
- Find spot
- Integration gap optimization
- Quadrupole scan
- Optimization
  - Focusing scan
  - Polarizer scan
  - Image rotation scan

Focusing



- Images are consistent with the optical model
- Large horizontal beam size makes possible very fast focusing

Polariser angle scan

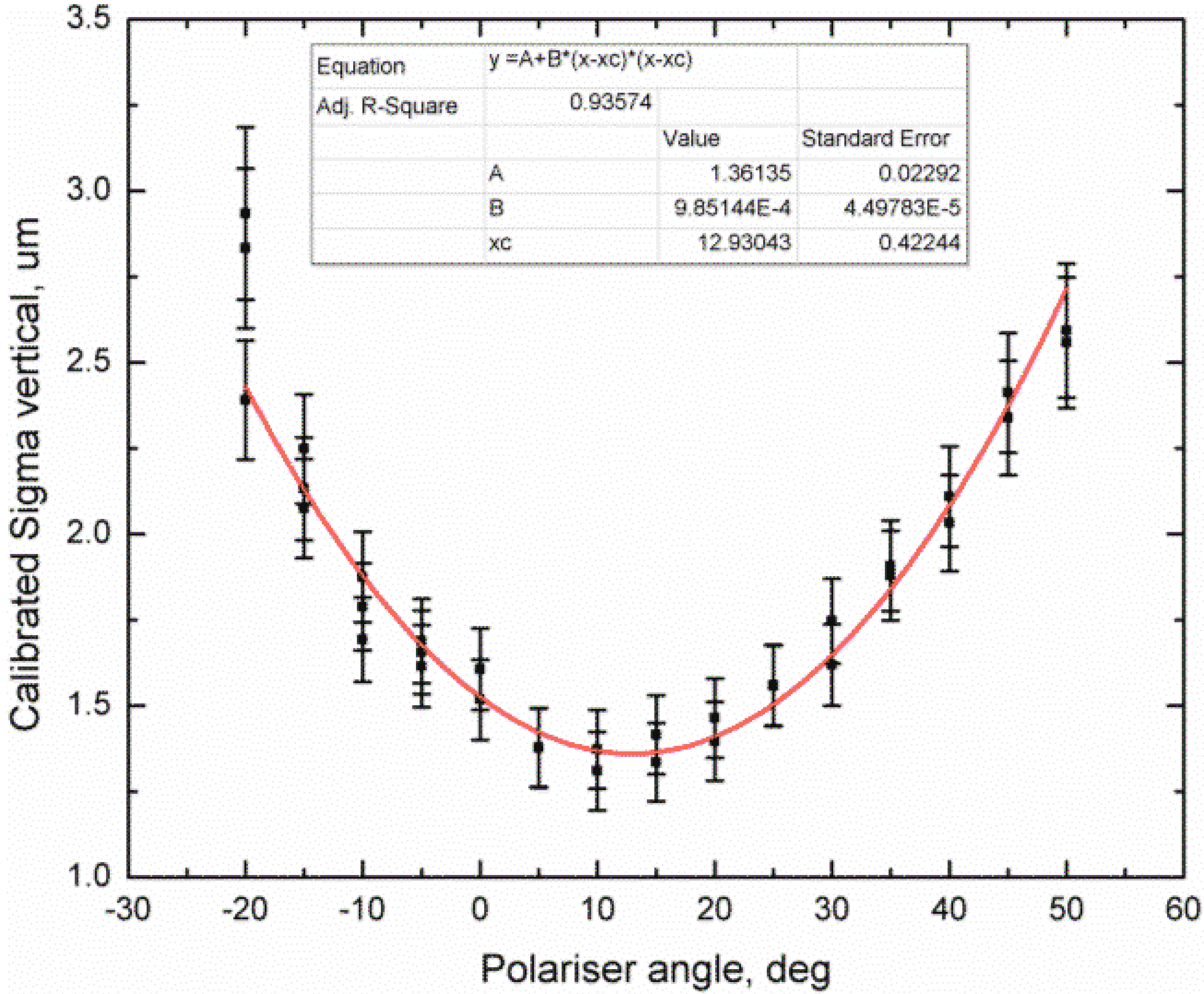
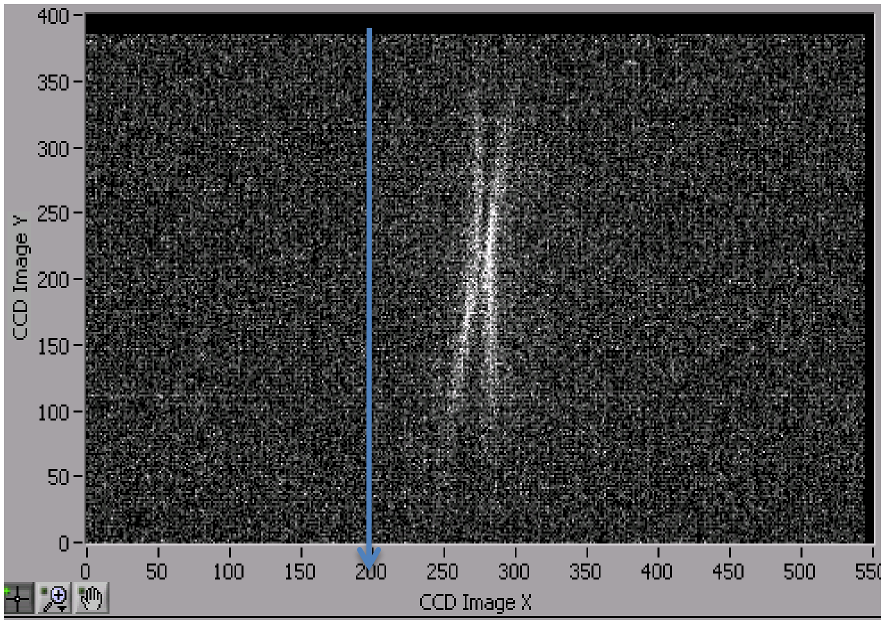
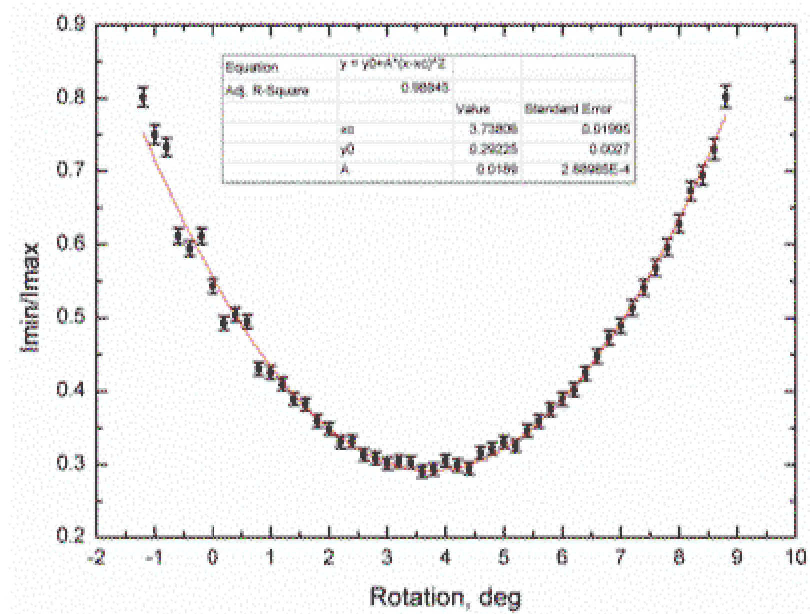


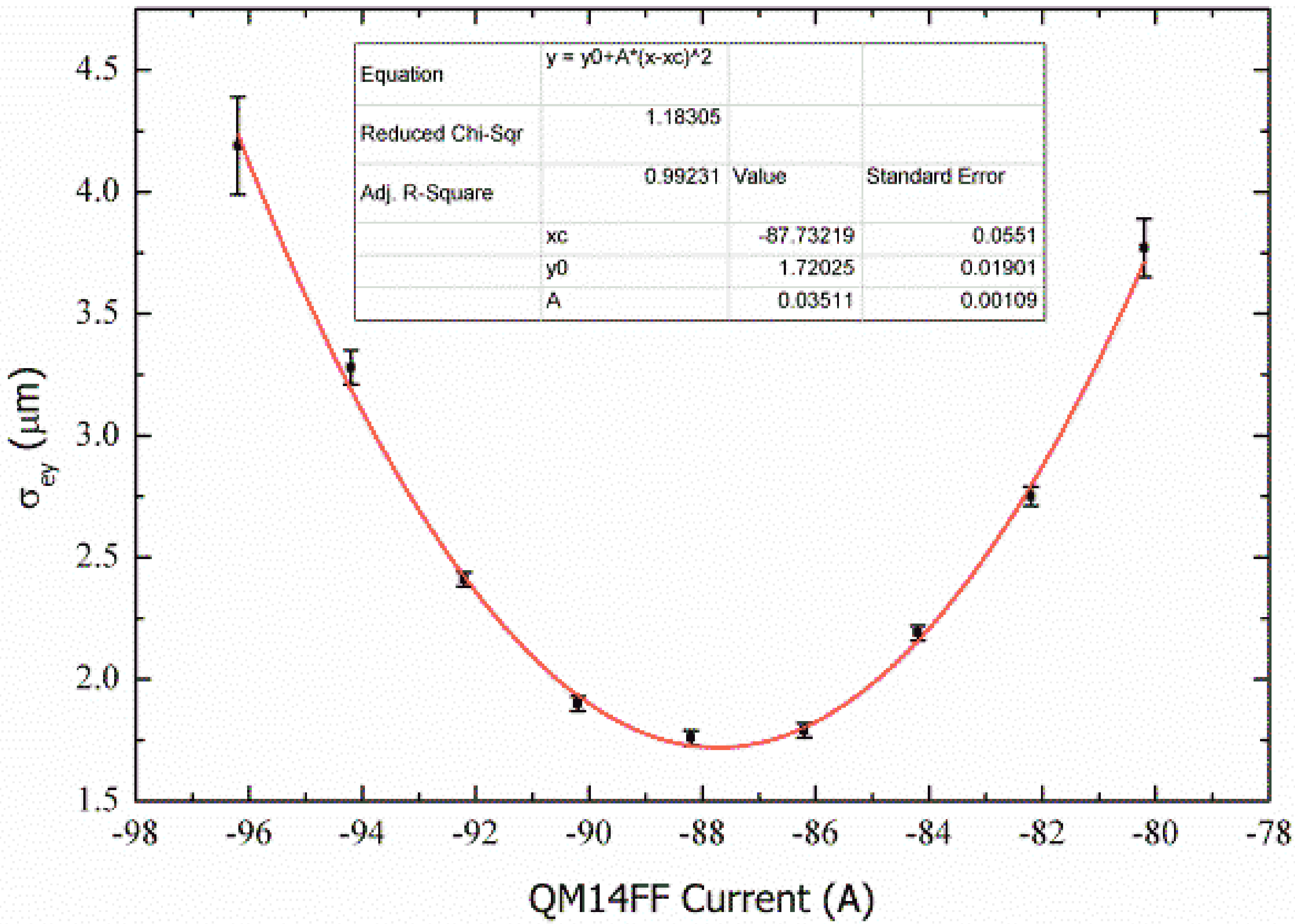
Image rotation analysis





- Many images were analyzed, rotation is always exist
- Removes the optical path misalignment effect
- Beam roll ??

Best scan example

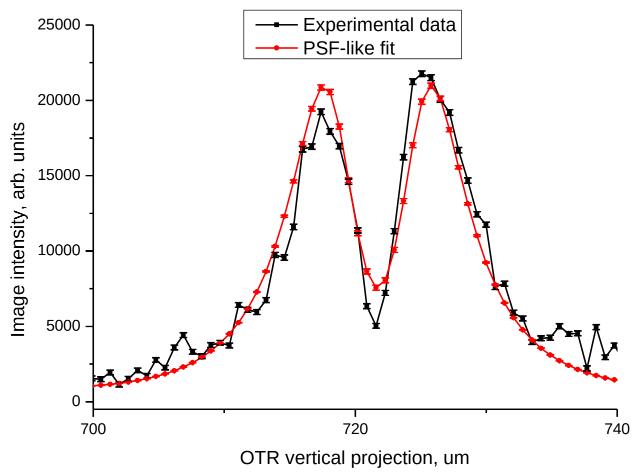


Future improvements and prospects

- Optical line re-arrangement
- Multi-elements microscope simulation is ongoing
- Modification of OTR PSF-like fit function

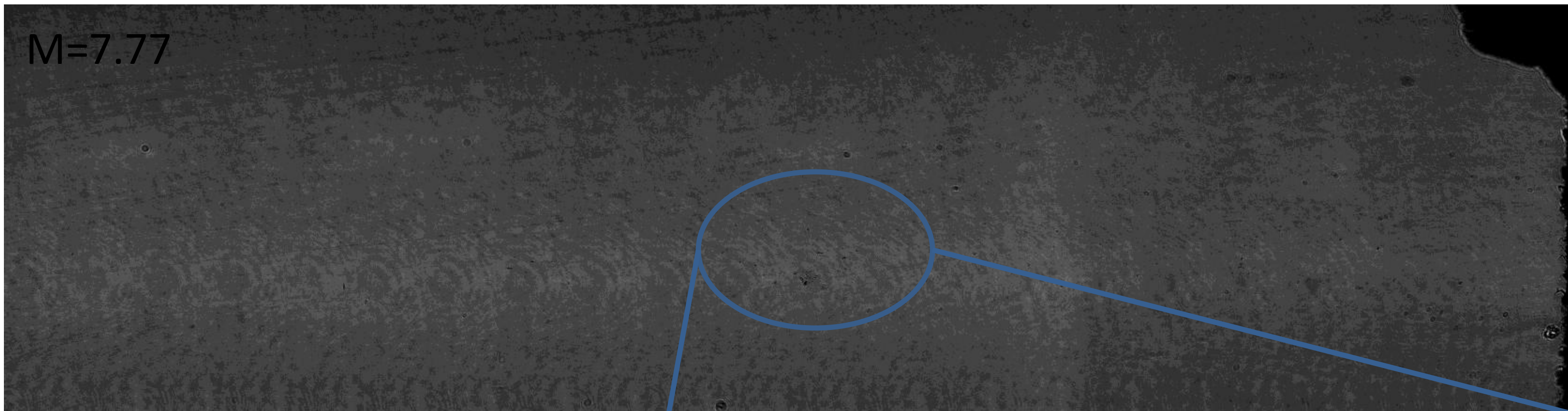
$$f(x) = a + \frac{b}{1+[c(x-\Delta x)]^4}\left[1 - e^{-2c^2\sigma^2}\cos[c(x-\Delta x)]\right]$$

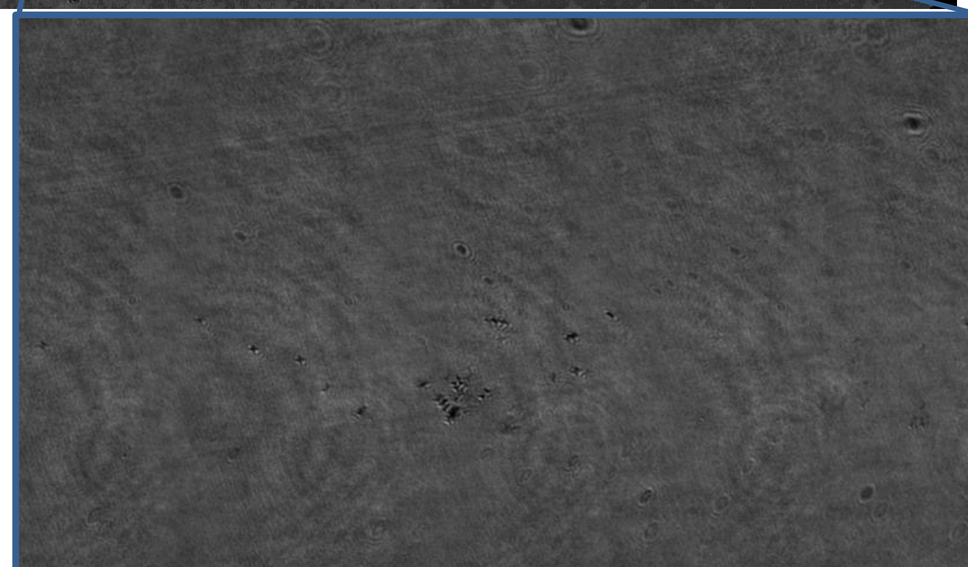
- Provides a better fit around two-lobe distribution dip
- Must define limits of a new variable parameter



Target damage

Microscopic panorama image of the OTR target. He-Ne laser illumination





- All damage was made at the previous OTR location.
- Damage threshold for this target was reached at:
  - 0.5 10^10 e/bunch
  - ~ 2um vertical
  - ~ 5um horizontal

Summary

- Many improvements has been introduced
- Routine operation of the monitor is achieved
- More work on analysis and simulations is required
- Possibility to analyse beam roll is considered