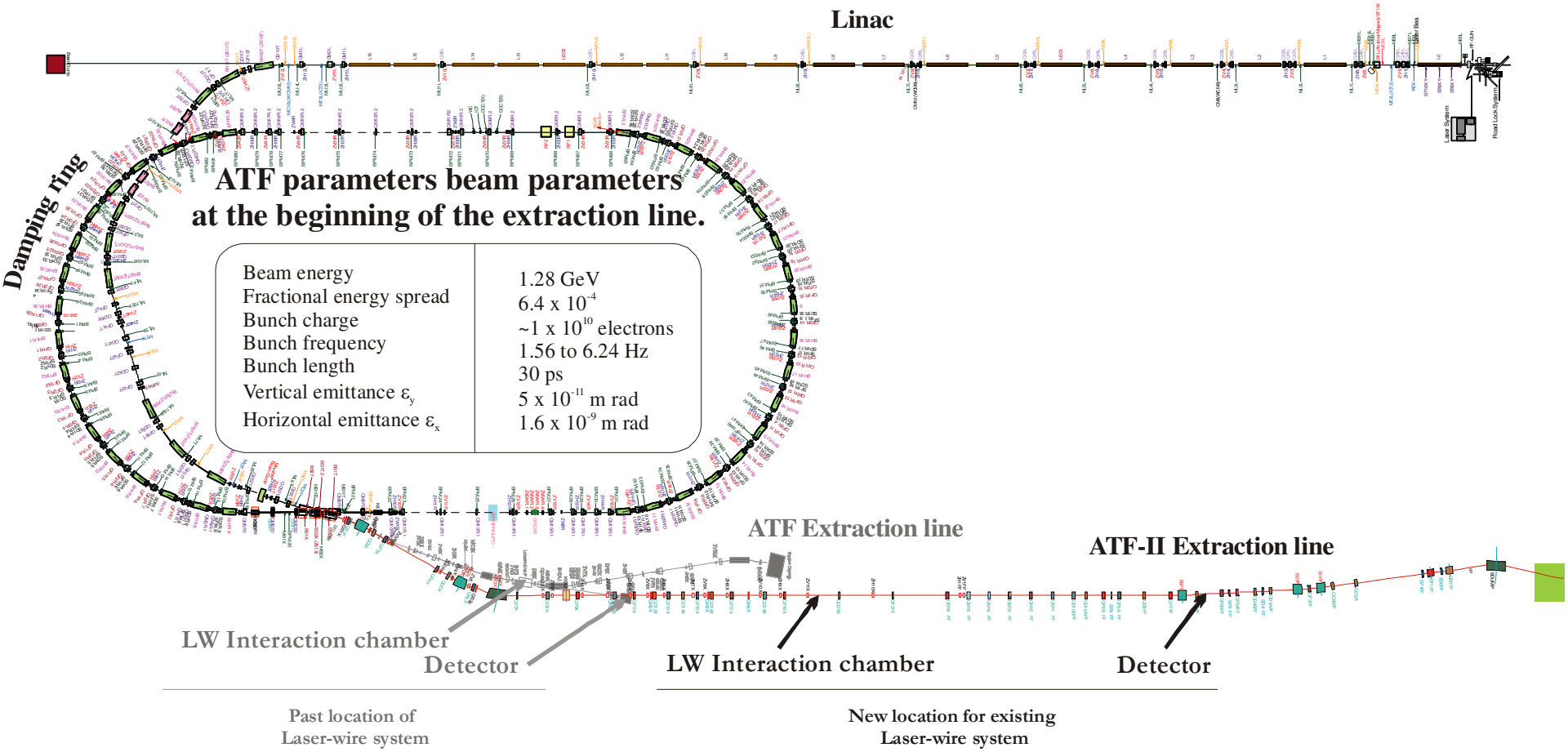
Royal Holloway
University of London

Sub-micrometer transverse electron beam size measurements using optical transition radiation

Pavel Karataev [a], Alexander Aryshev [b], Stewart Boogert [a]
David Howell [c], Nobihiro Terunuma [b], Junji Urakawa [b]

[a] John Adams Institute at Royal Holloway, Egham, Surrey, TW20 0EX, UK
[b] KEK, 1-1 Oho, Tsukuba, Ibaraki 305-0801, Japan
[c] John Adams Institute at Oxford University, Nuclear and Astrophysics Laboratory, Keble Road, Oxford OX1 3RH, UK

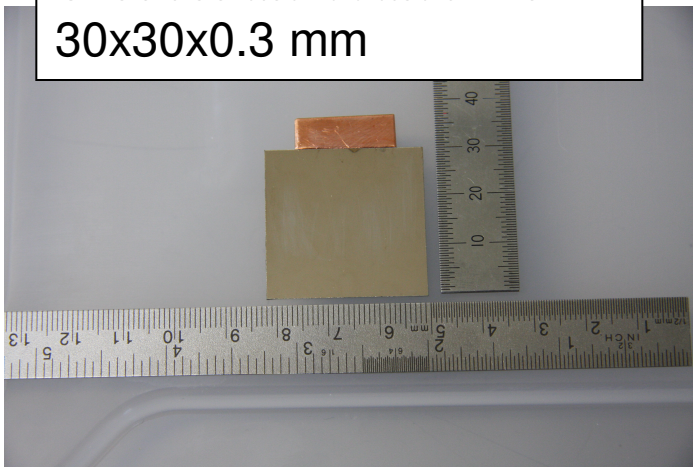
ATF-II

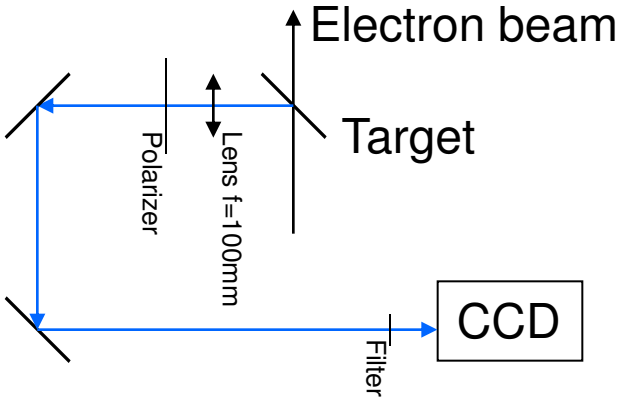


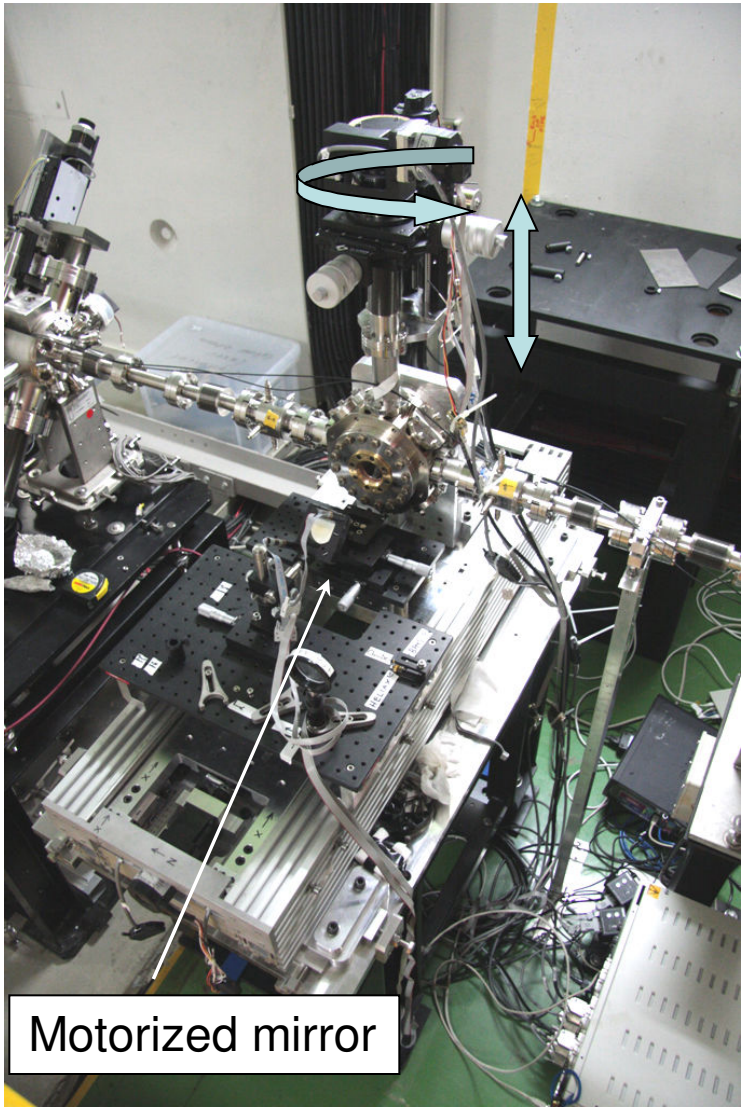
ATF parameters beam parameters at the beginning of the extraction line.

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

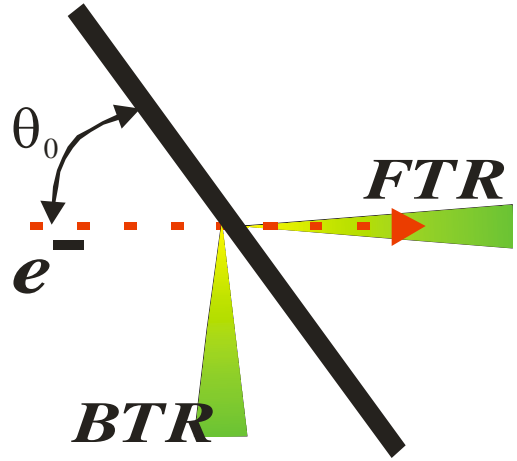
Interaction Chamber







Optical Transition Radiation

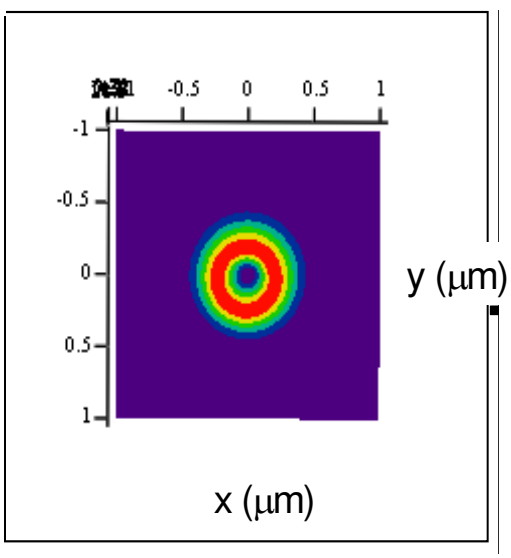


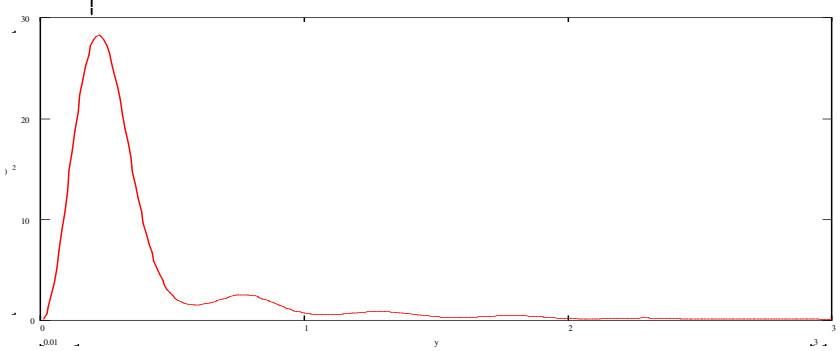
Transition radiation (TR) appears when a charged particle crosses a boundary between two media with different dielectric constants.

The resolution is determined by the source dimensions (**Point Spread Function**) induced by a single particle plus distortion caused by the optical system (diffraction of OTR tails)

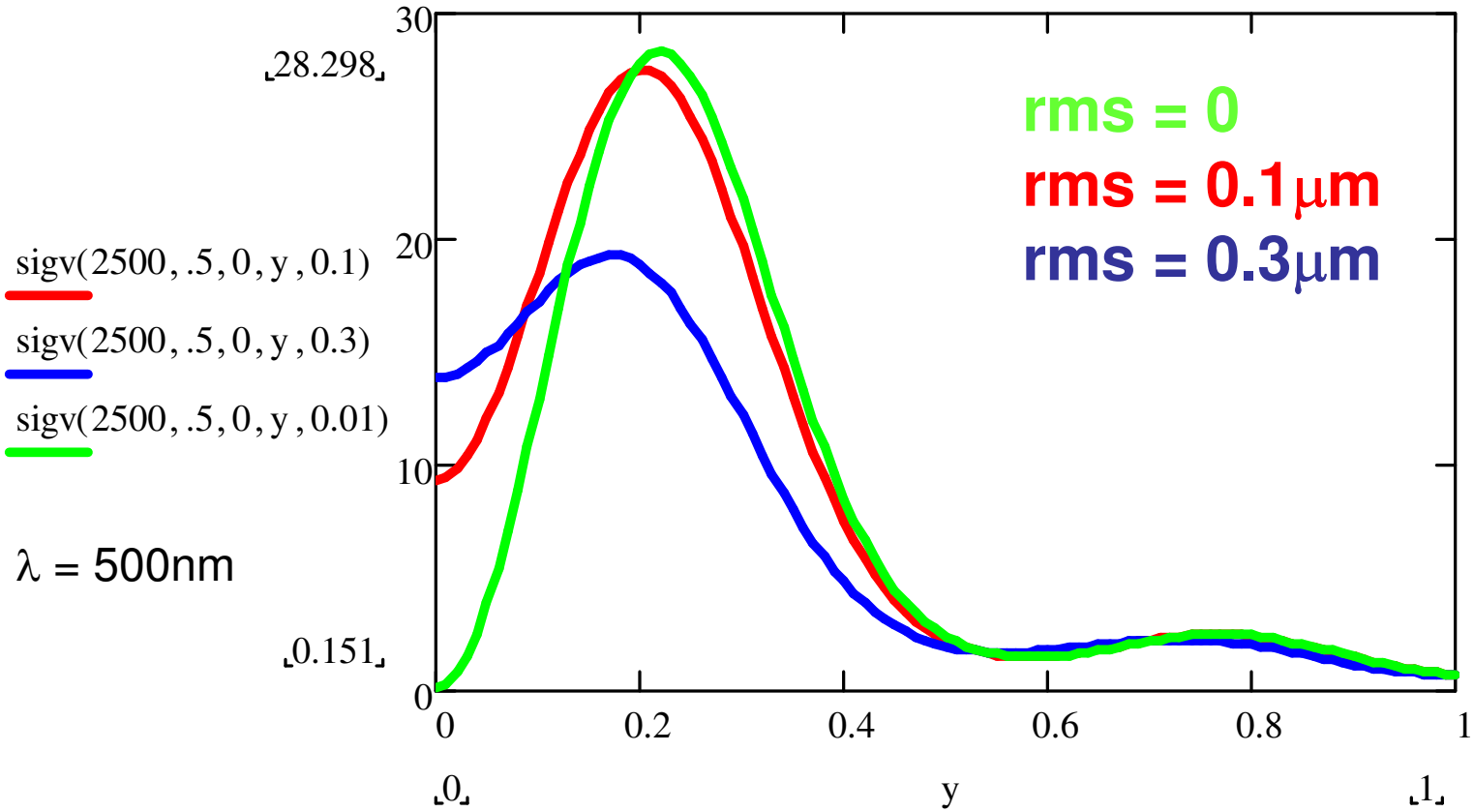
M. Castellano, et al., NIMA 435(1999)297

$$S = \text{const}\left|\frac{2\pi}{\gamma\lambda}K_1\left(\frac{2\pi}{\gamma\lambda}\sqrt{x^2+y^2}\right) - \frac{J_0\left(\frac{2\pi}{\lambda}\sqrt{x^2+y^2}\right)}{\sqrt{x^2+y^2}}\right|^2$$





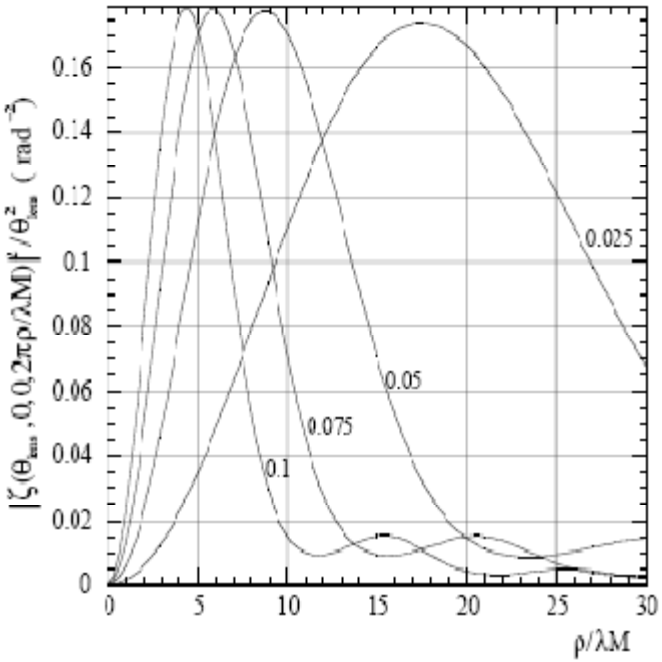
Beam size effect (idealized model)



λ = 500nm

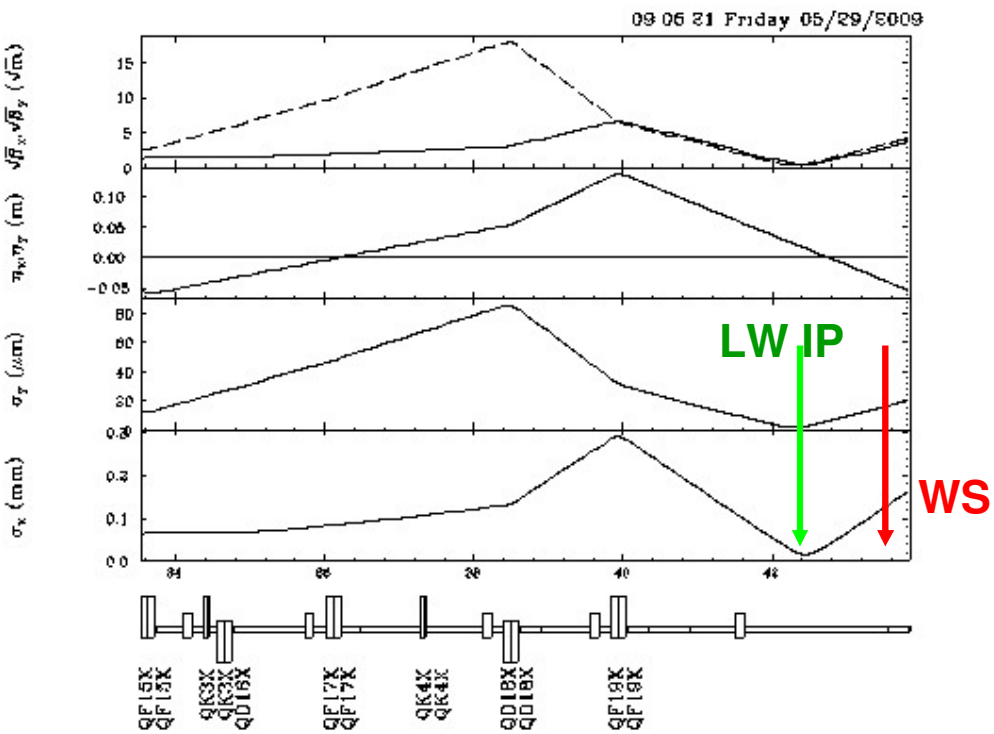
Phenomena leading to PSF distortion

- Diffraction of OTR tails
- Chromatic aberrations
- Spherical aberrations



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

LW electron beam optics test



- Predictions:

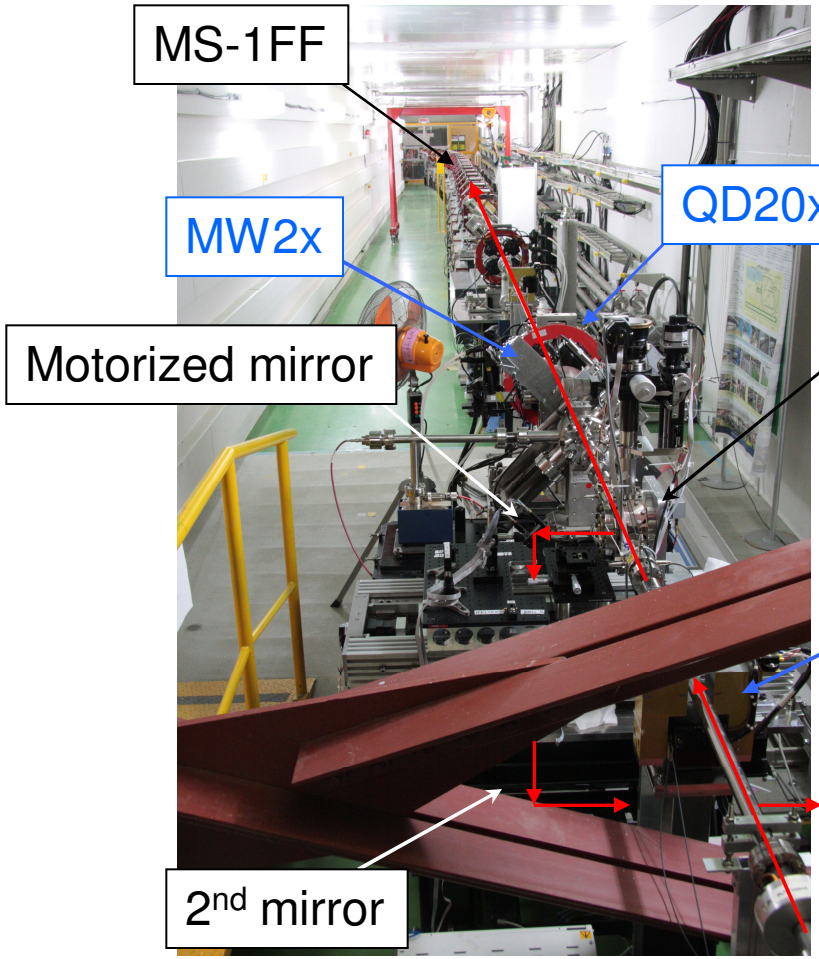
at LW IP	at MW2X
σ_x = 20μm	20μm
σ_y = 1.7μm	2.3μm

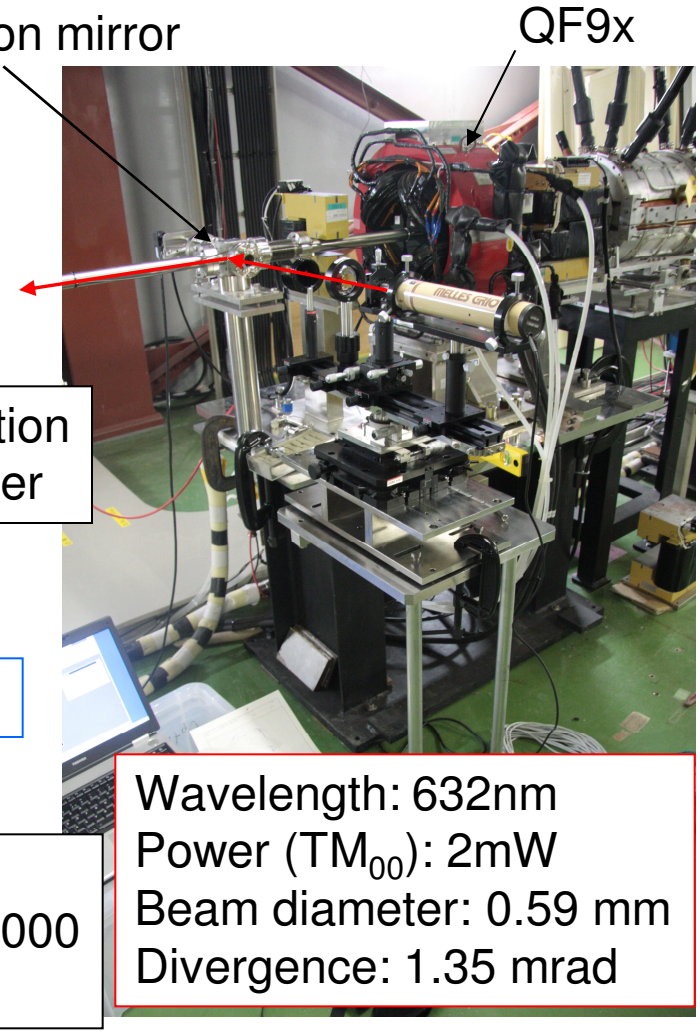
- Measurements at MW2X

σ_x = 30μm

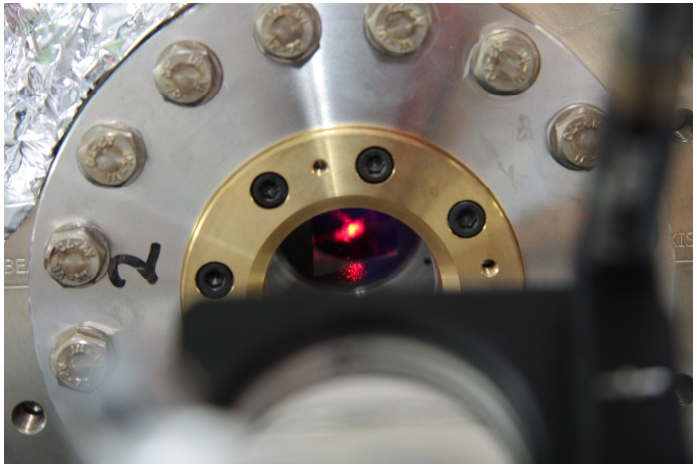
σ_y = 3.4μm

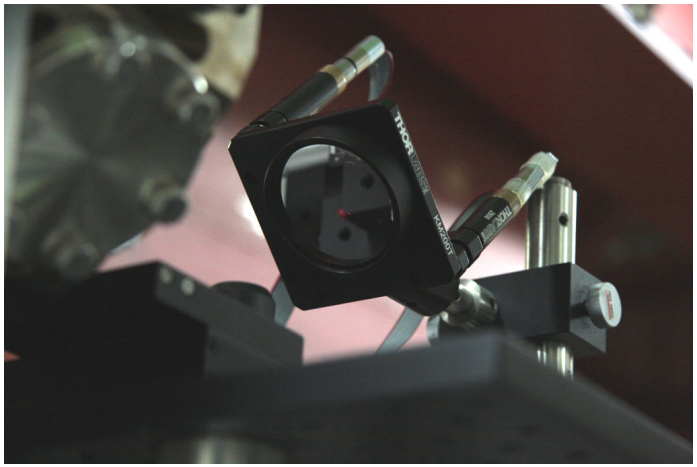
Alignment

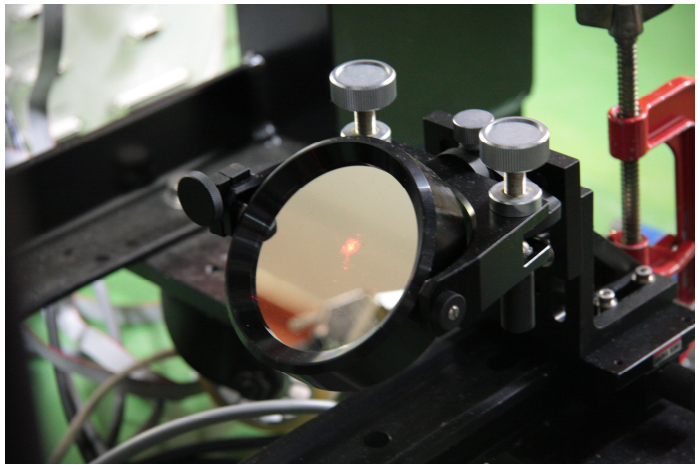

MS-1FF
MW2x
QD20x
Motorized mirror
Interaction Chamber
ZV11x
CCD
Alta E4000
16 bit
2nd mirror

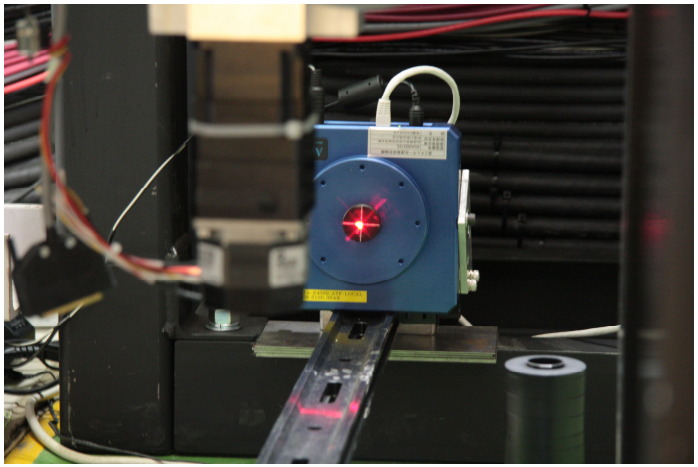

Insertion mirror
QF9x
Wavelength: 632nm
Power (TM_{00}): 2mW
Beam diameter: 0.59 mm
Divergence: 1.35 mrad

Alignment



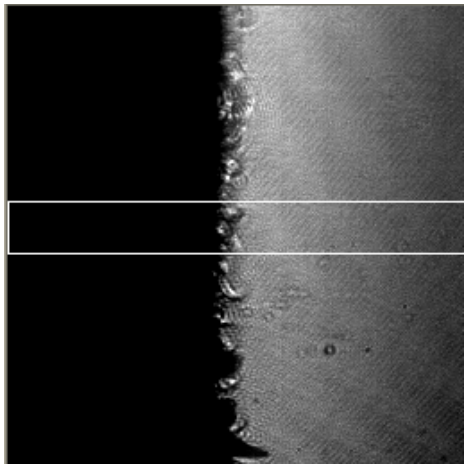




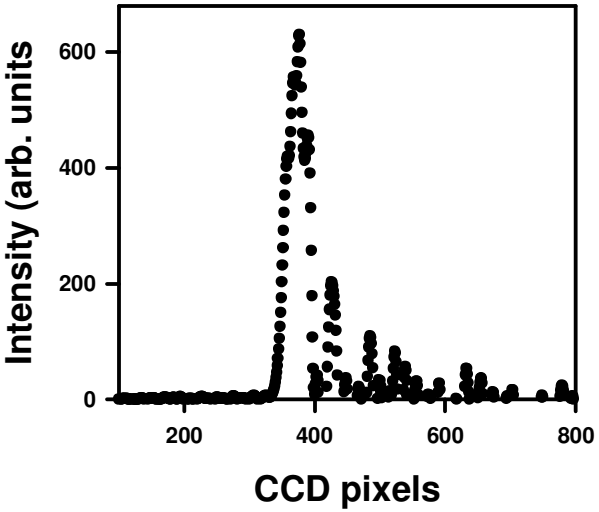


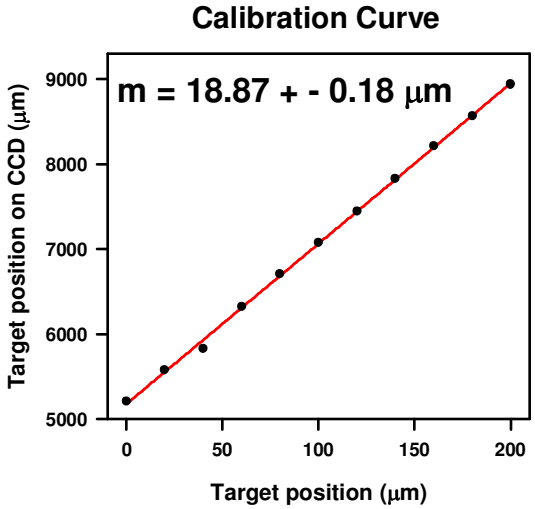
Calibration of the optical system

CCD Image of the target edge



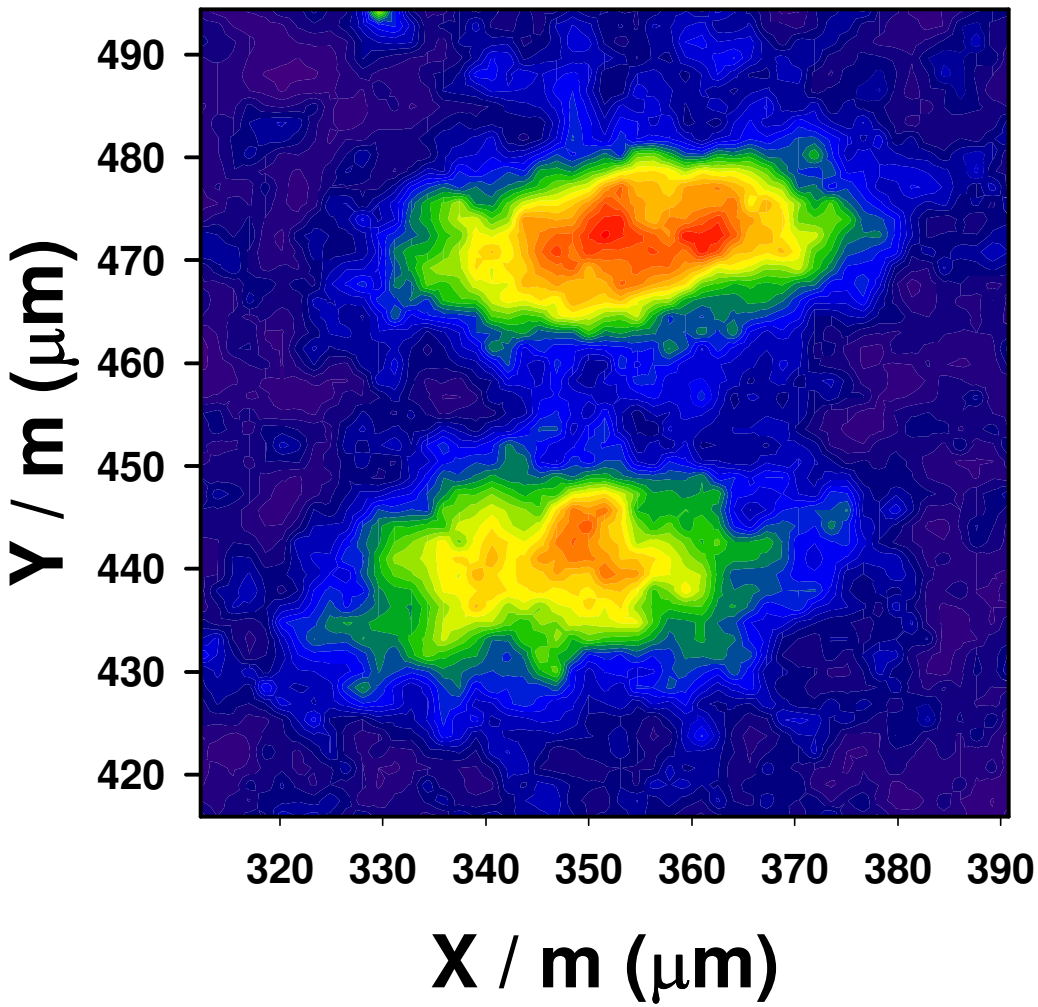
Differentiated slope



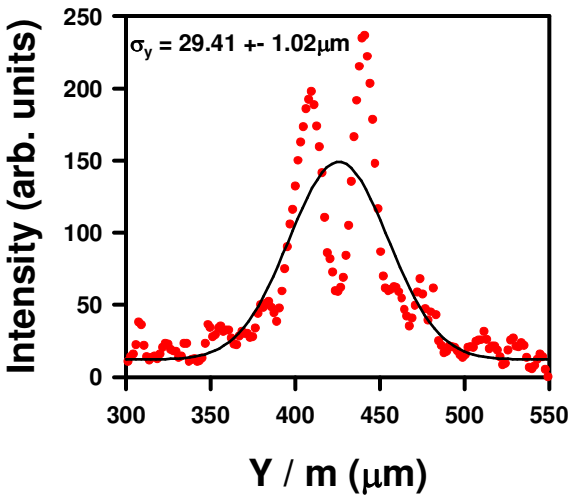


Magnification factor of an optical System 18.87

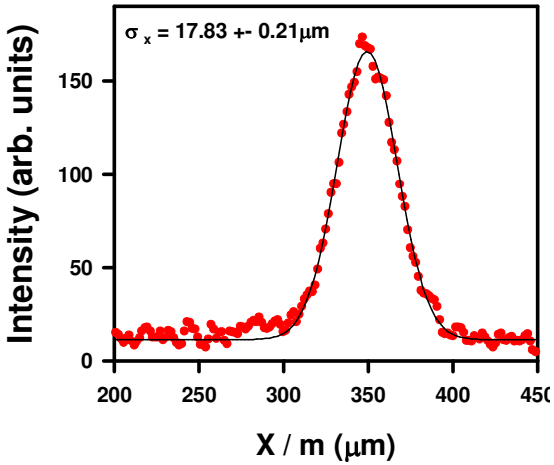
OTR image with a polarizer and optical filter



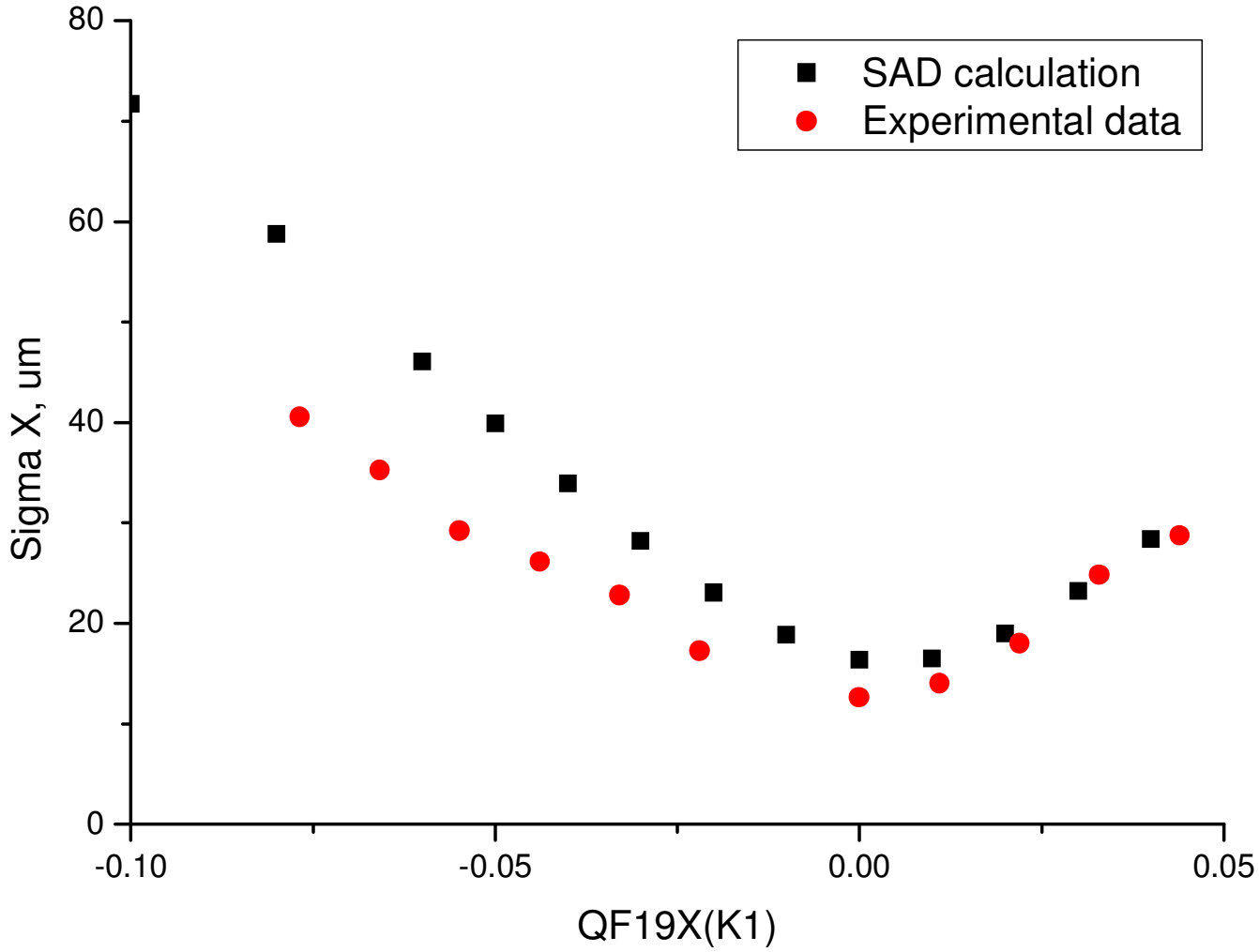
Vertical projection



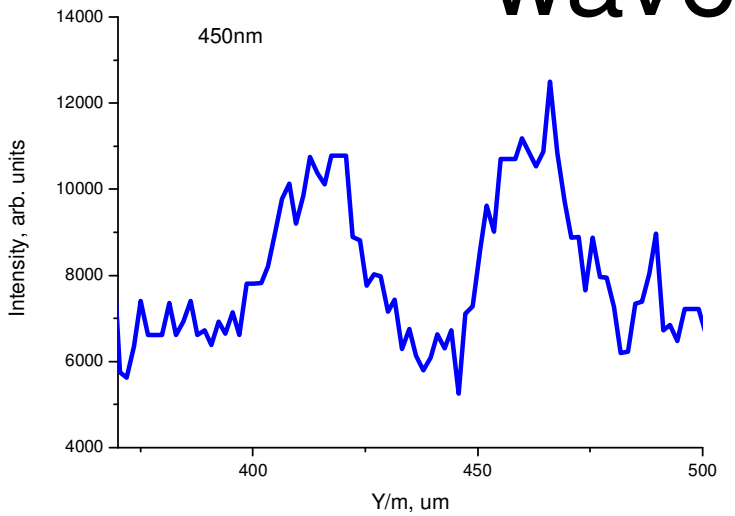
Horizontal projection

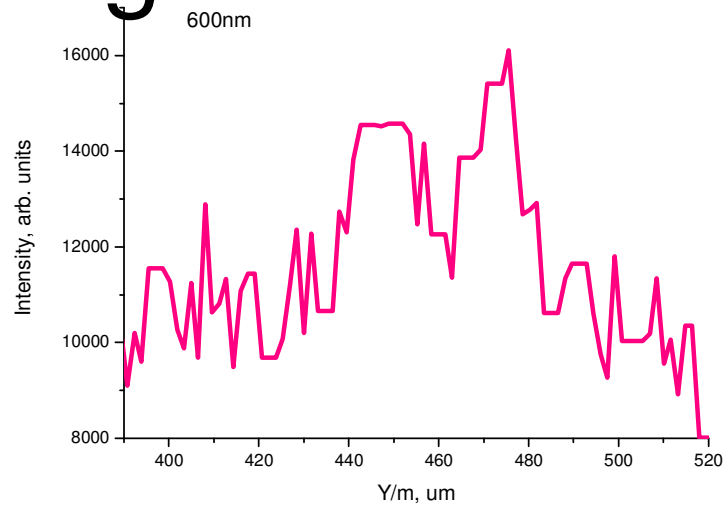


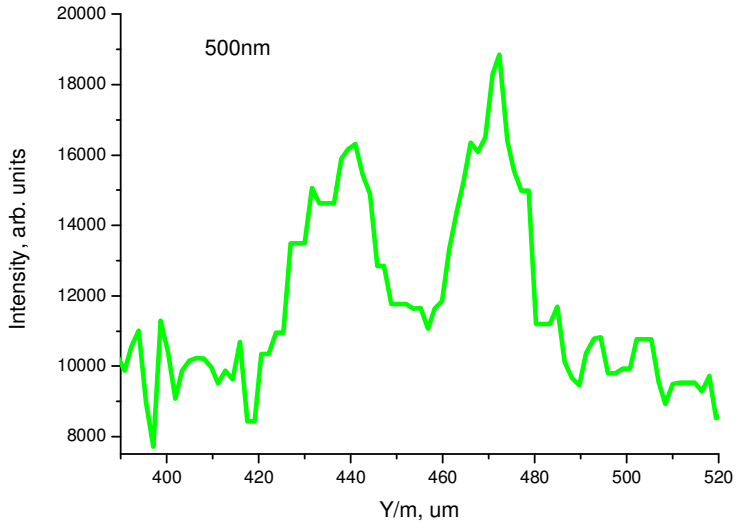
Horizontal beam size effect



OTR Measurements for different wavelengths

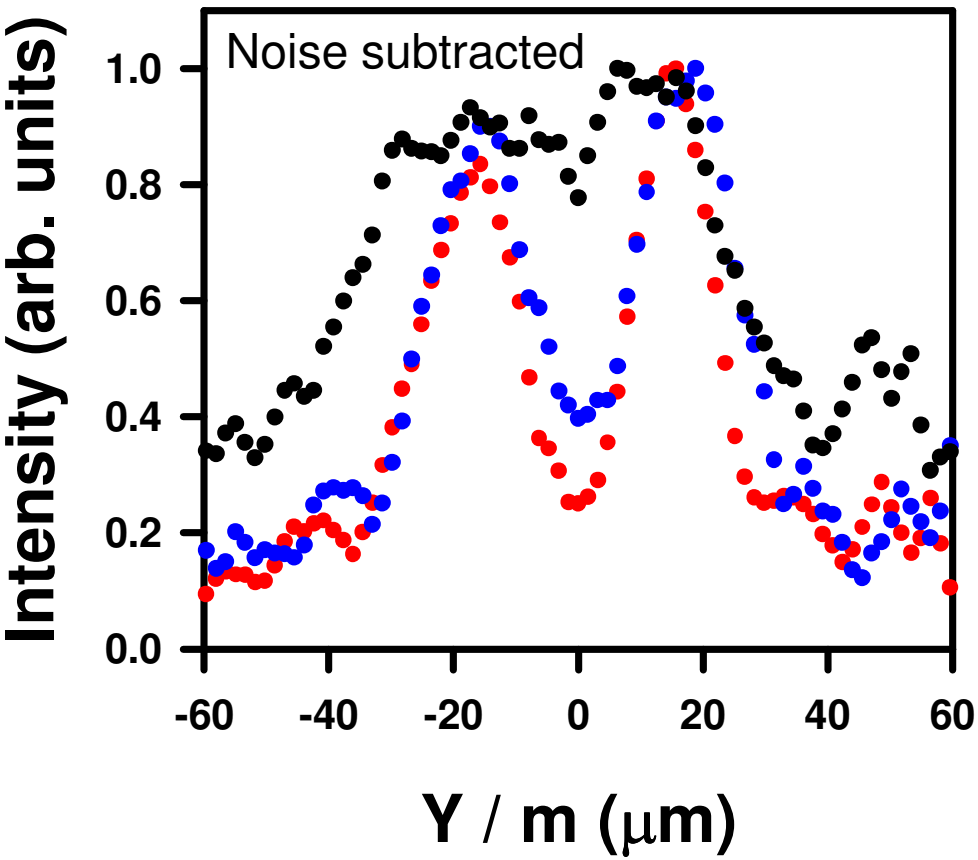






- Increasing wavelength, distribution becomes narrower in contrast to the diffraction effect
- Probably this is aberration effect

Vertical Beam Size effect



QD18X = 29.56A
QD18X = 29.86A
QD18X = 30.16A

SAD predictions

σ_y = 1.7μm

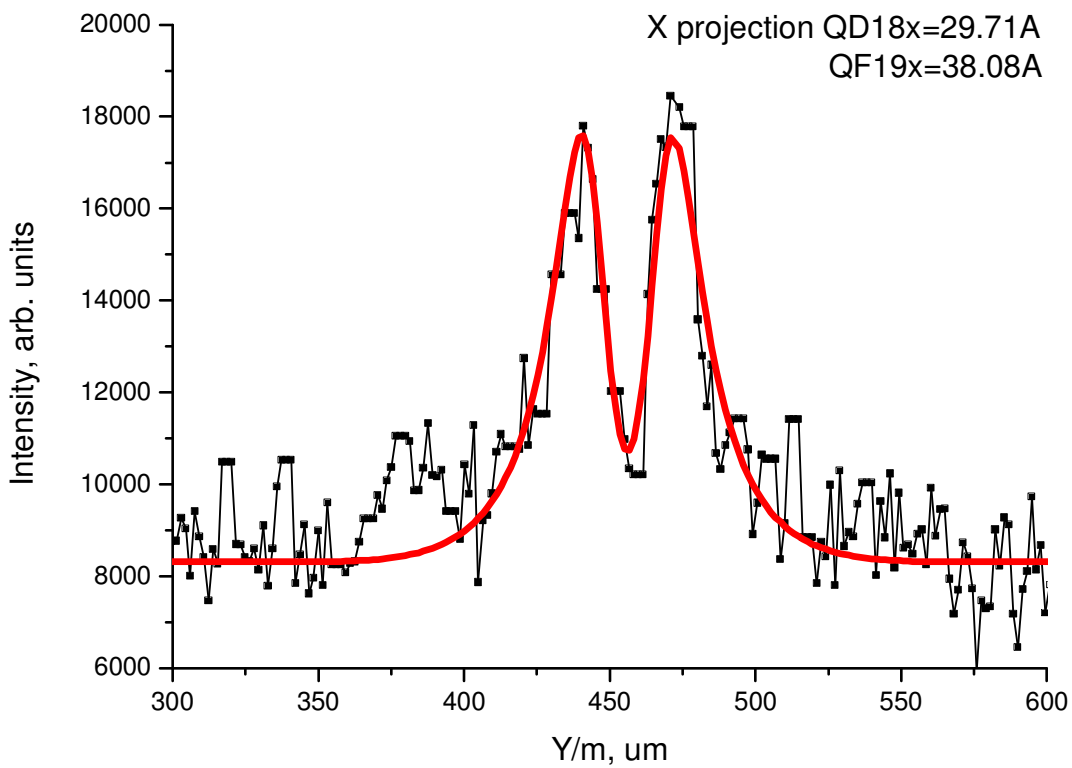
σ_y = 3.4μm

σ_y = 7.2μm

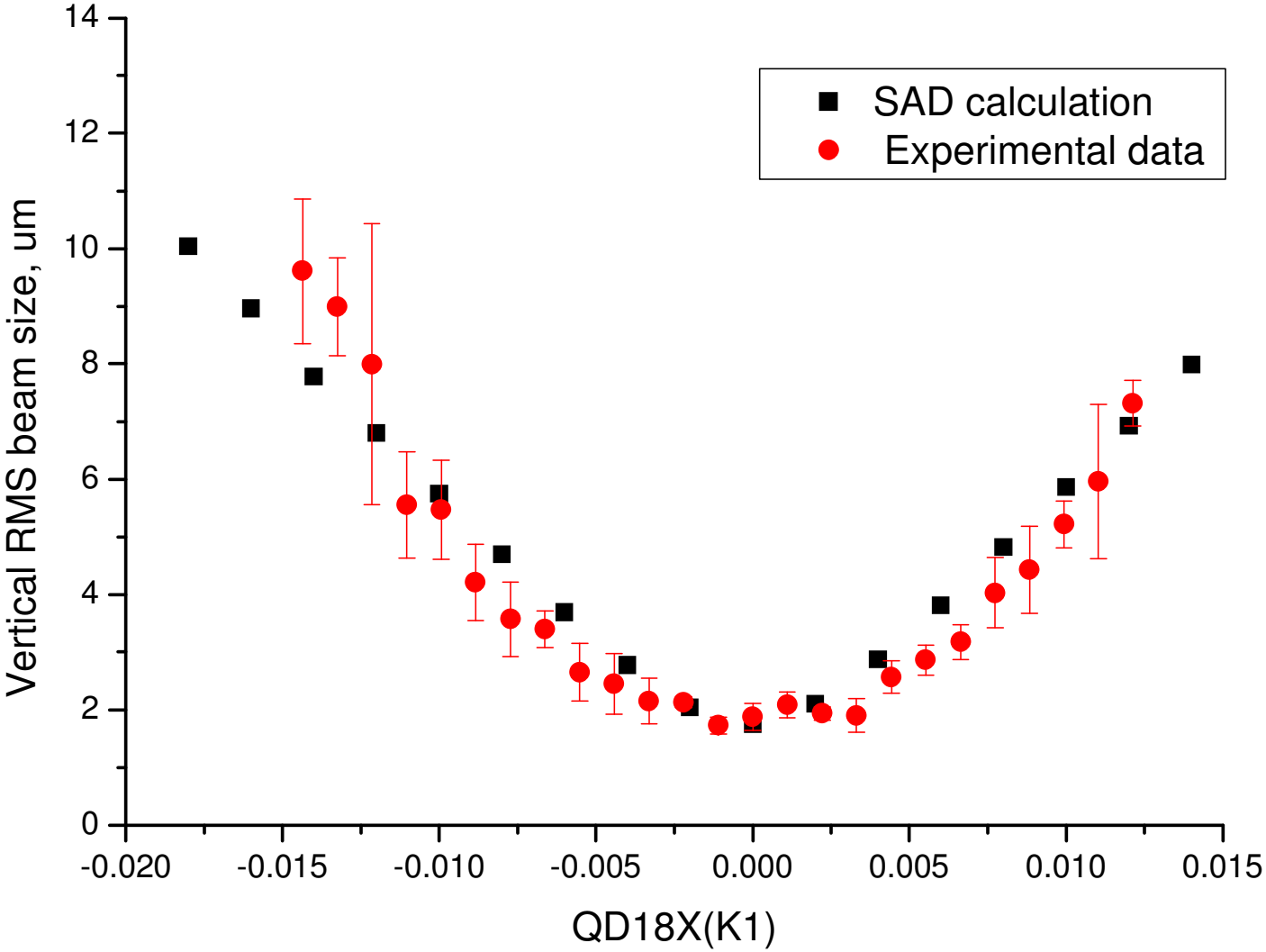
New Fit function

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

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.



QD18X scan

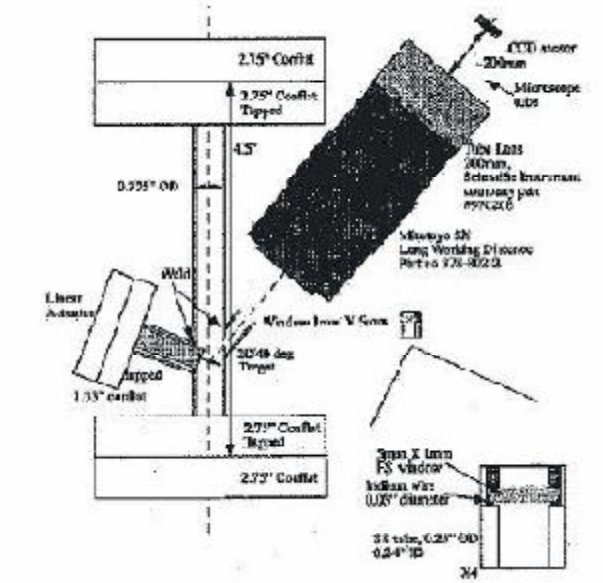

SAD calculation
Experimental data
Vertical RMS beam size, um
QD18X(K1)
0
2
4
6
8
10
12
14
-0.020
-0.015
-0.010
-0.005
0.000
0.005
0.010
0.015

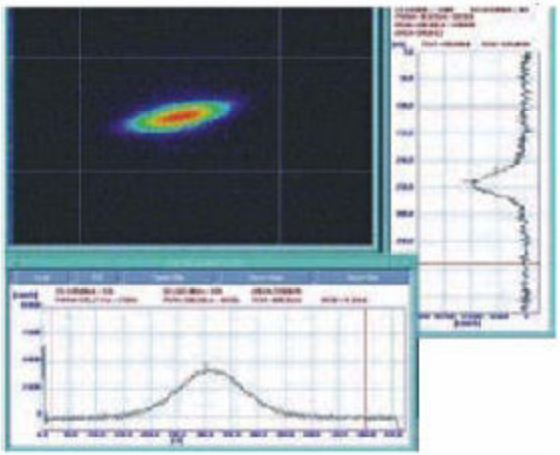
Summary and future plans

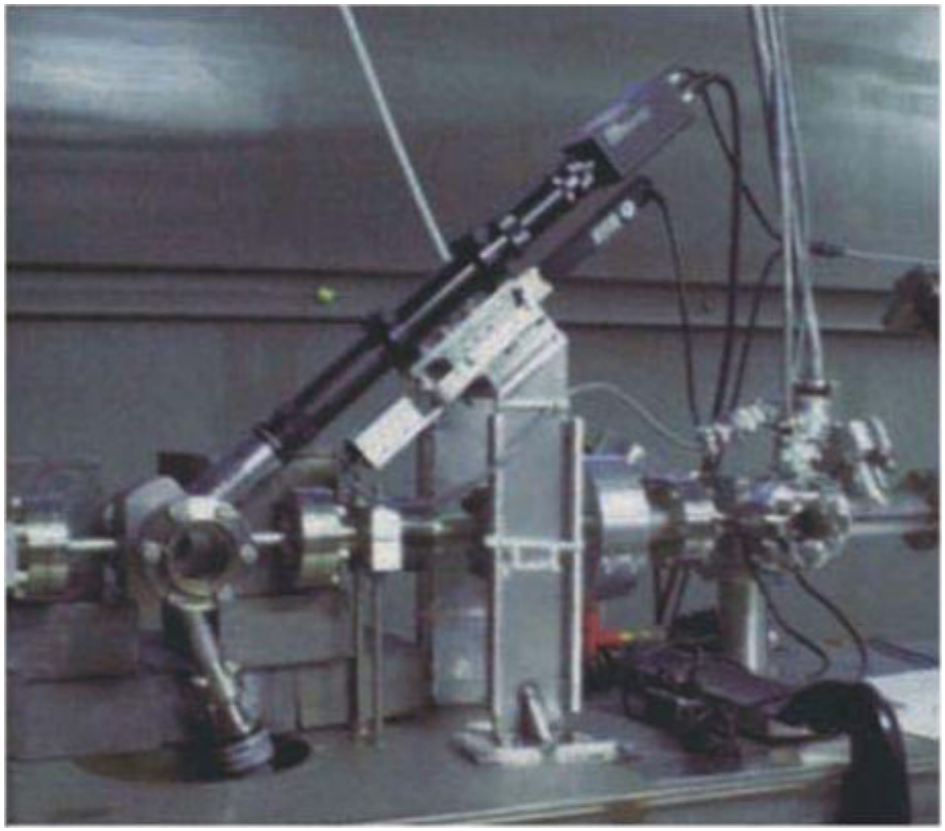
- First observation of OTR PSF
- Chromatic aberrations are severe and must be taking into account when resolution for conventional beam size monitor is estimated
- Novel beam size measurement technique

- Efforts toward:
  - Optimization of the optical system
  - Better understanding of the beam size effect

SLAC OTR monitor at KEK-ATF





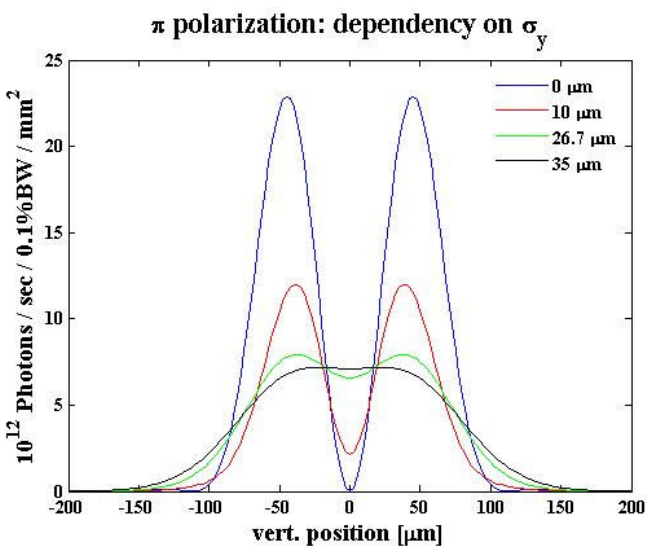


Very high resolution for an OTR monitor (~2μm) predicted by the theory but only ~5.5μm spot was actually measured.

Optical Imaging @ SLS (PSI)

imaging with vertically polarized optical radiation

smearing out of minimum with increasing vert. beam size σ_y



σ_y from peak/valley ratio

σ_x from fit

good agreement with independent pinhole measurements

SRW calculation , parameters similar to SLS monitor:

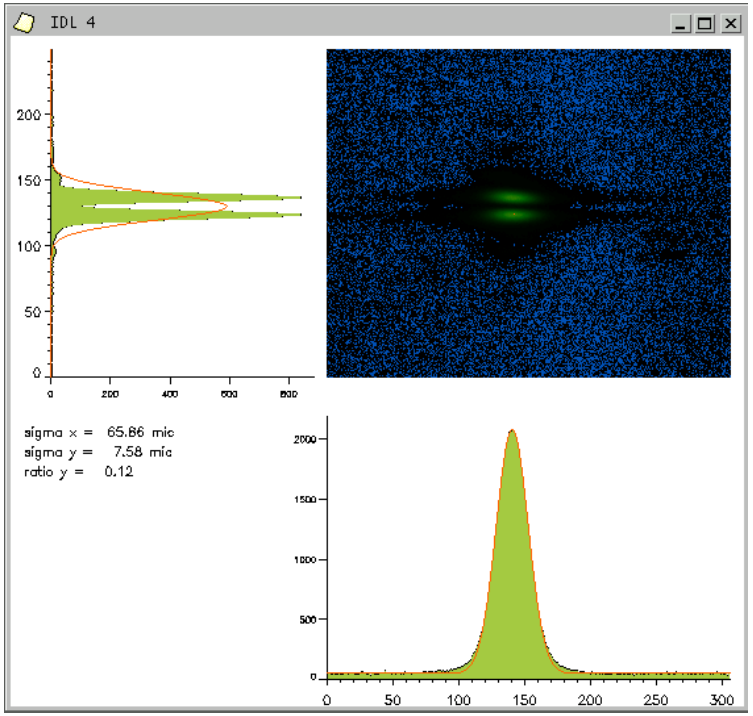
E = 2.4 GeV

λ = 365 nm

1:1 imaging

monitor screenshot:

courtesy of Å. Andersson, SLS



A. Åndersson et al., Proc.EPAC 2006, Edinburgh, Scotland, p.1223

Å. Andersson, DIPAC 2007