Experimental investigations of backward transition radiation characteristics in extreme ultraviolet region

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Talk overview

- Introduction and Motivation
- Theoretical model
- Experimental setup
- Experimental results

INTRODUCTION

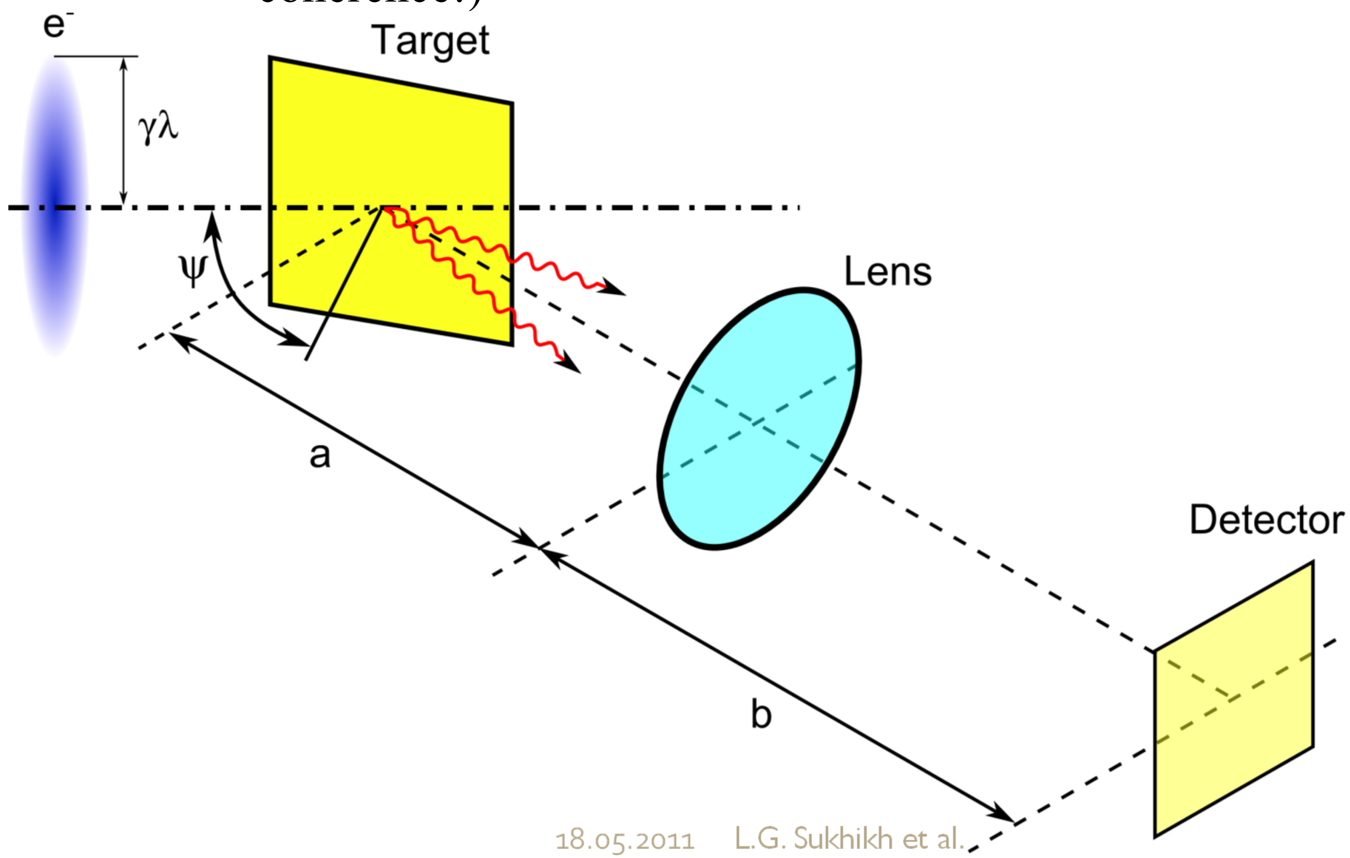
OTR beam size monitor

- beam diagnostics: backward OTR (reflection of virtual photons)

  typical setup: image beam profile with optical system

  → beam image and measurements of beam shape and size

- advantage: fast single shot measurement, linear response (neglect coherence!)

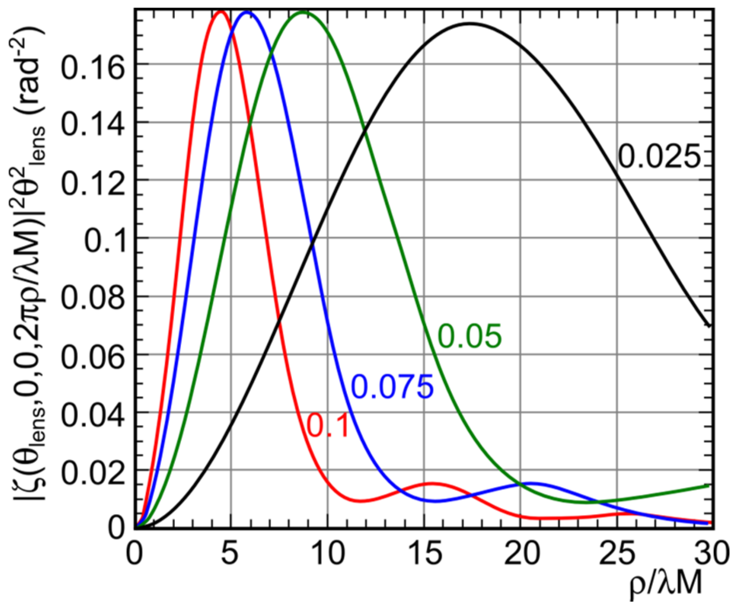


Limits of OTR diagnostics: Coherent emission limit

- Coherent OTR was measured at LCLS at SLAC in Stanford (USA), at FLASH at DESY in Hamburg (Germany), at BELLA at LBNL in Berkley (California, USA)…
- Already discussed by S. Wesch.

Limits of OTR diagnostics: Resolution limit

PSF



M. Castellano and V.A. Verzilov "Spatial resolution in optical transition radiation beam diagnostics", PRST-AB 1, 062801 (1998).

No “nice” beam image if beam size is <~ 3 um if one uses OTR

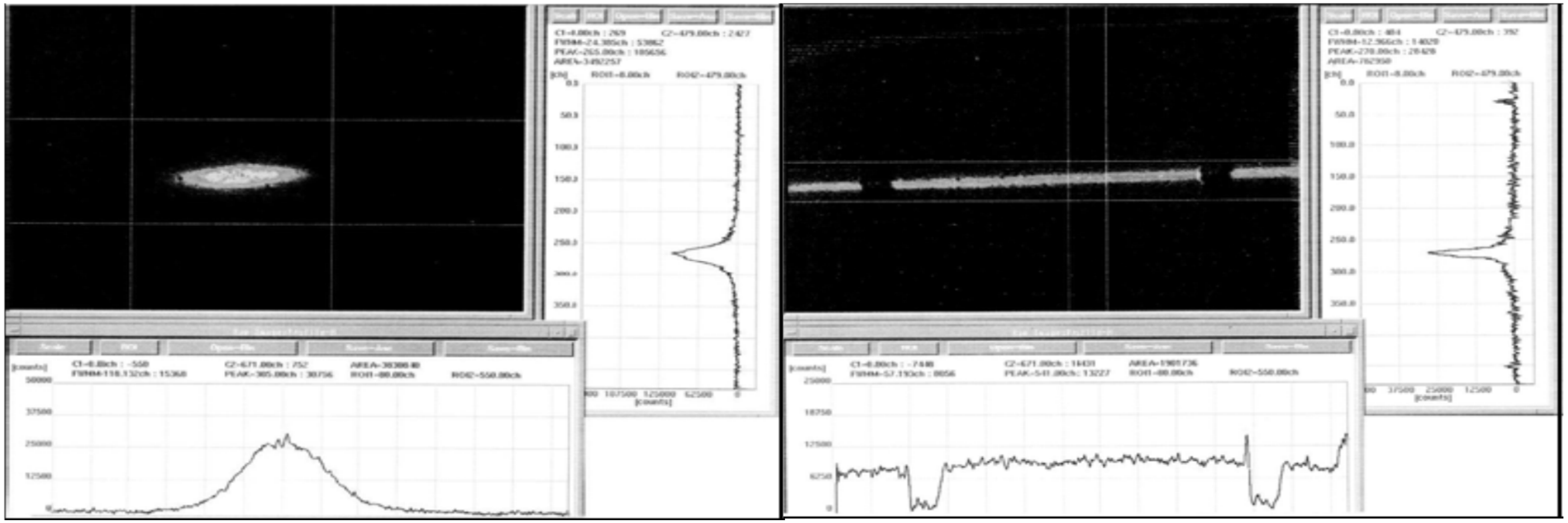
A Very High Resolution Optical Transition Radiation Beam Profile Monitor // Ross M. et al. SLAC-PUB-9280 July 2002

Optical wavelengths

λ~550 nm

$FWHM = 10\mu$

$FWHM = 5.8\mu$



PSF measurement at KEK-ATF2

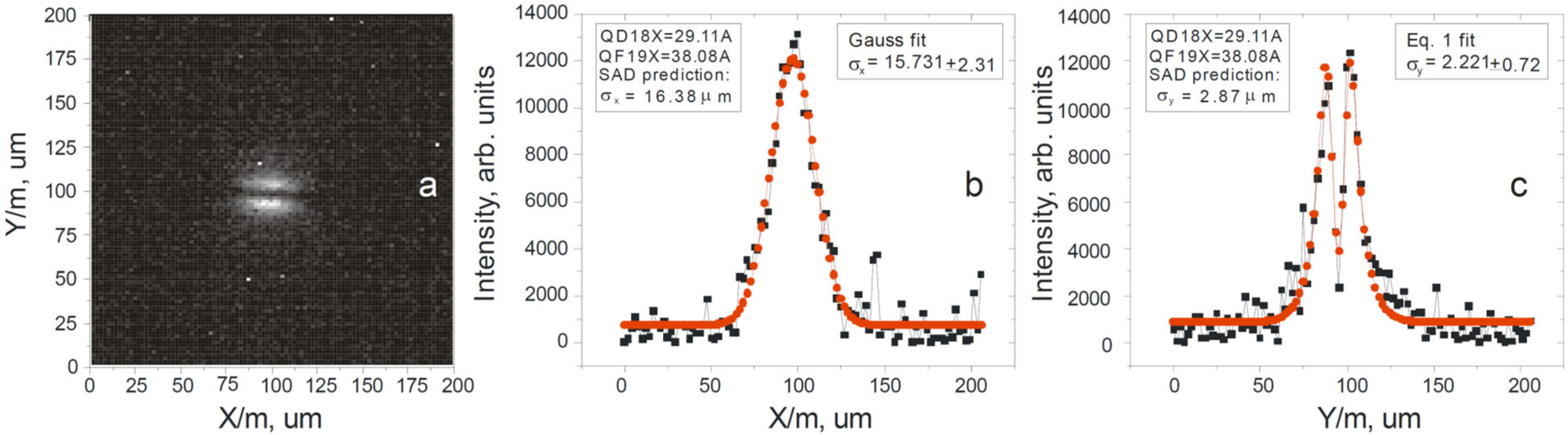


Figure 3: CCD image of the OTR taken with linear polarizer and 500 nm optical filter (a) and two image projections: horizontal (b) and vertical (c).

Aryshev, A., Terunuma, N., Urakawa, J., Boogert, S.T., Karataev, P., Howell, D., "SUB-MICROMETER RESOLUTION TRANSVERSE ELECTRON BEAM SIZE MEASUREMENT SYSTEM BASED ON OPTICAL TRANSITION RADIATION", Proc. IPAC '10, Kyoto, (Japan), 193-195 (2010).

EUV region

- Earlier it was proposed to use Backward Transition Radiation in EUV region to avoid above mentioned problems.
- The wavelength is smaller and resolution may be much better.
- The wavelength is smaller and coherence effect should not be so pronounced.

THEORETICAL MODEL

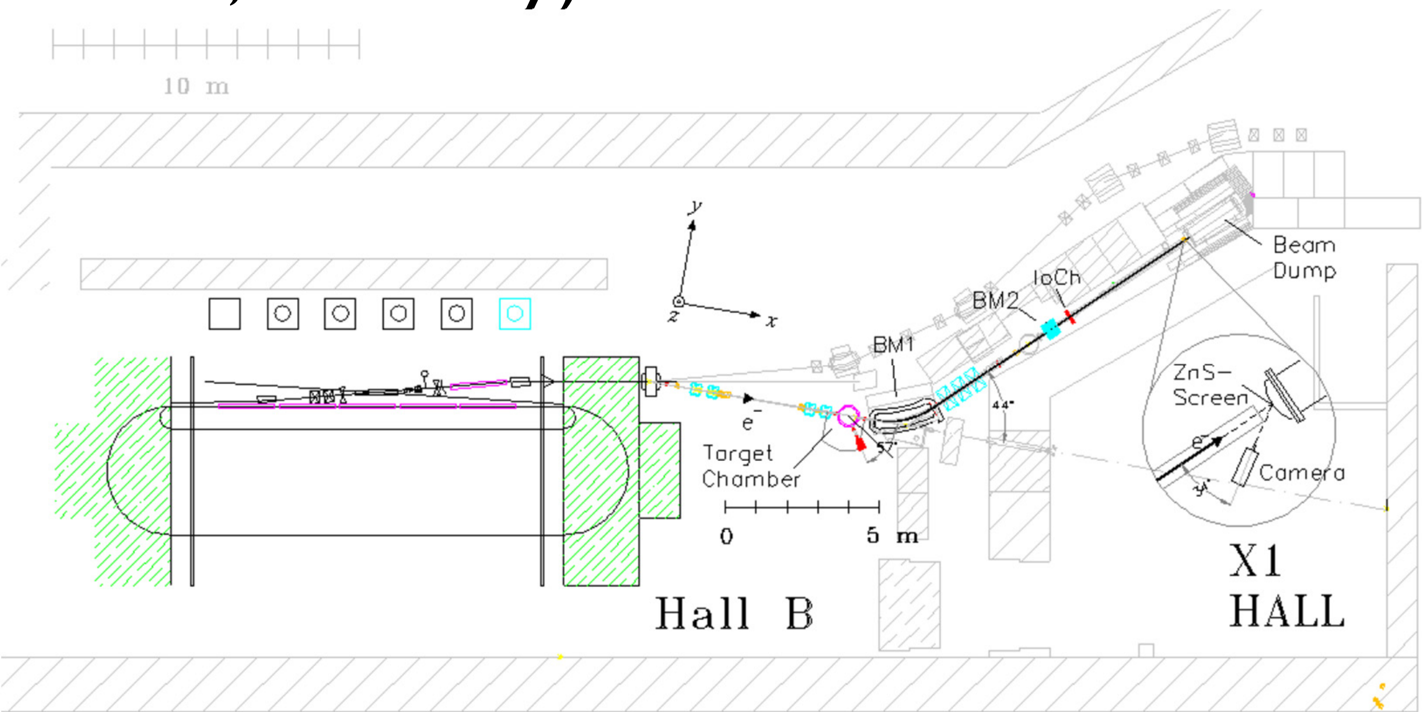
- Theoretical calculations of the BTR generation is based on ideally reflecting model and Fresnel reflection coefficients for Molybdenum.

$$\frac{d^2W}{\hbar d\omega d\Omega} = \frac{cr^2}{\hbar}\left[\left|R_\sigma E_y\right|^2 + \left|R_\pi\right|^2\left(\left|E_x\right|^2 + \left|E_z\right|^2\right)\right]$$

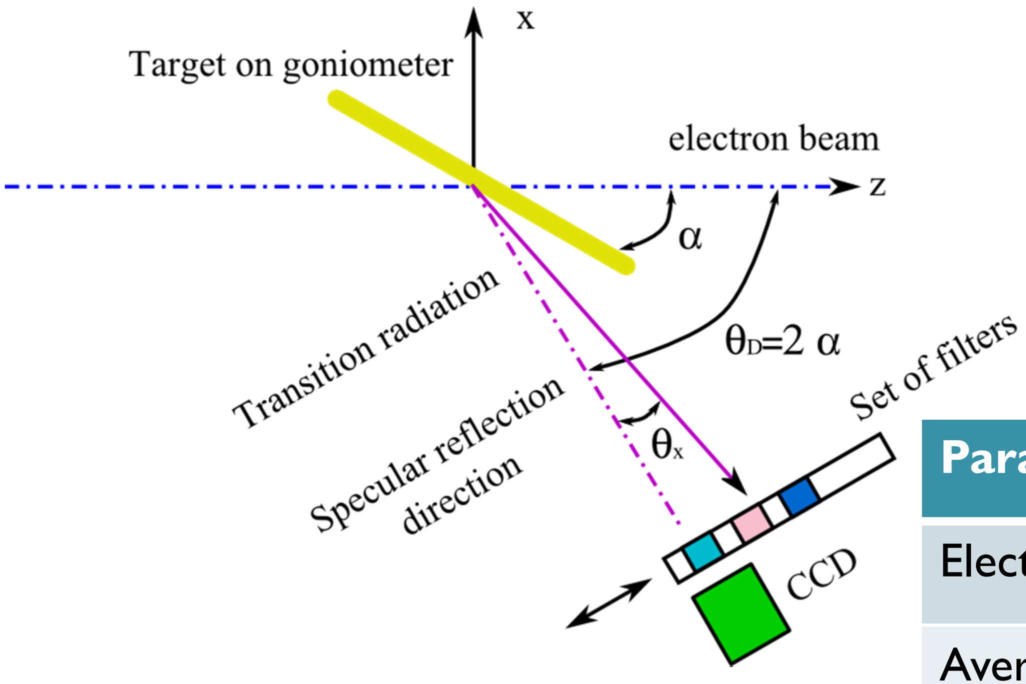
EXPERIMENTAL SETUP

Experimental scheme

- The experiment was carried out using the electron beam of Mainz Microtron MAMI (Institute of Nuclear Physics, University of Mainz, Germany)



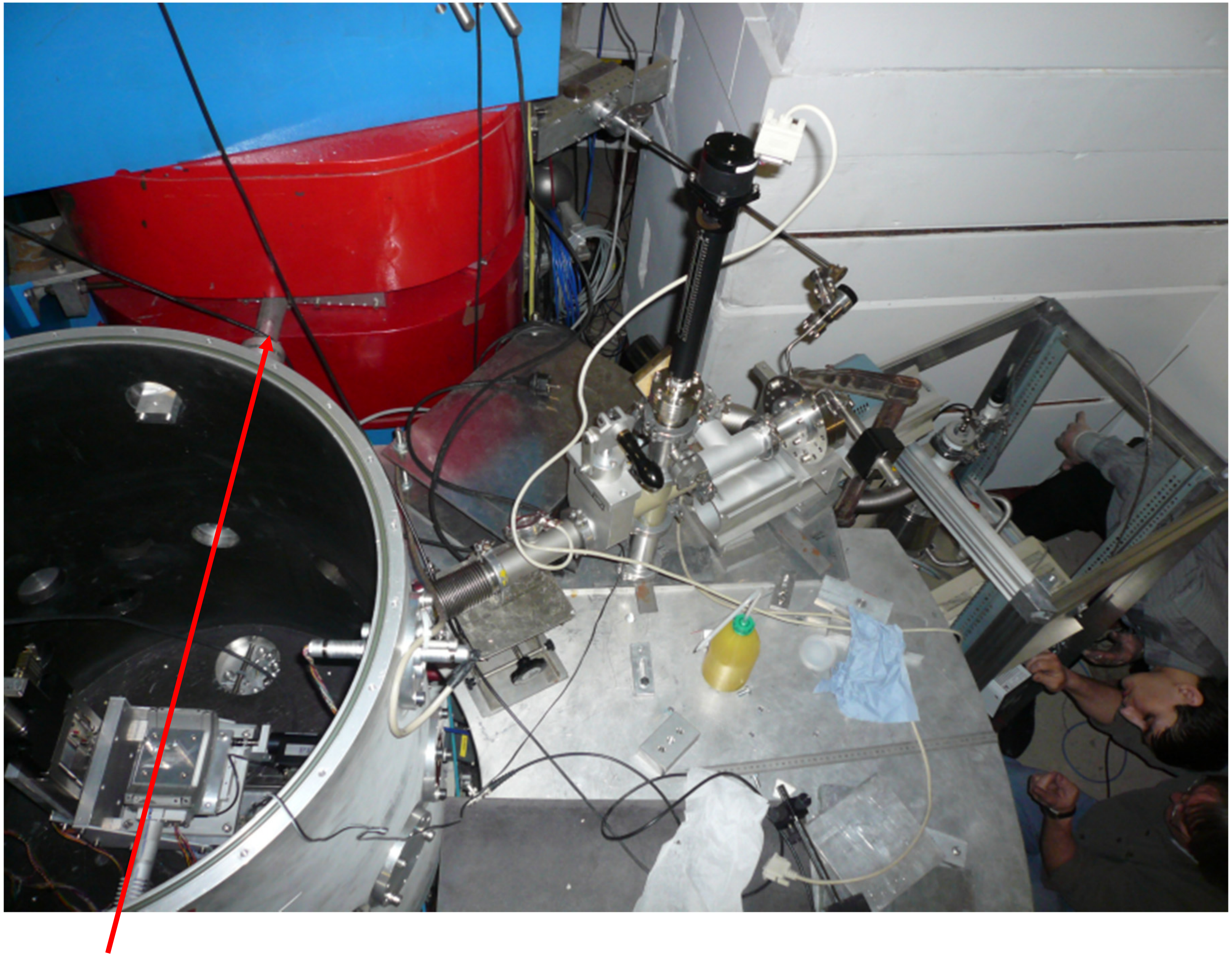
Experimental scheme



Beam parameters

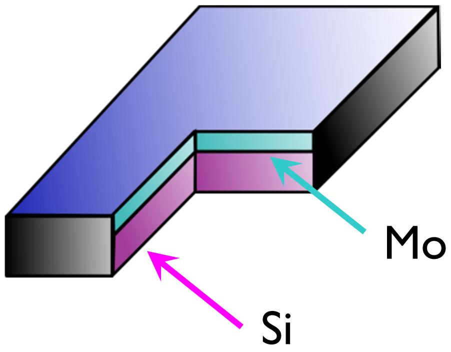
Parameter	Value
Electron energy	855 MeV
Average beam current	52 nA
Pulse duration	0.8 sec
Pulse spacing	3 sec

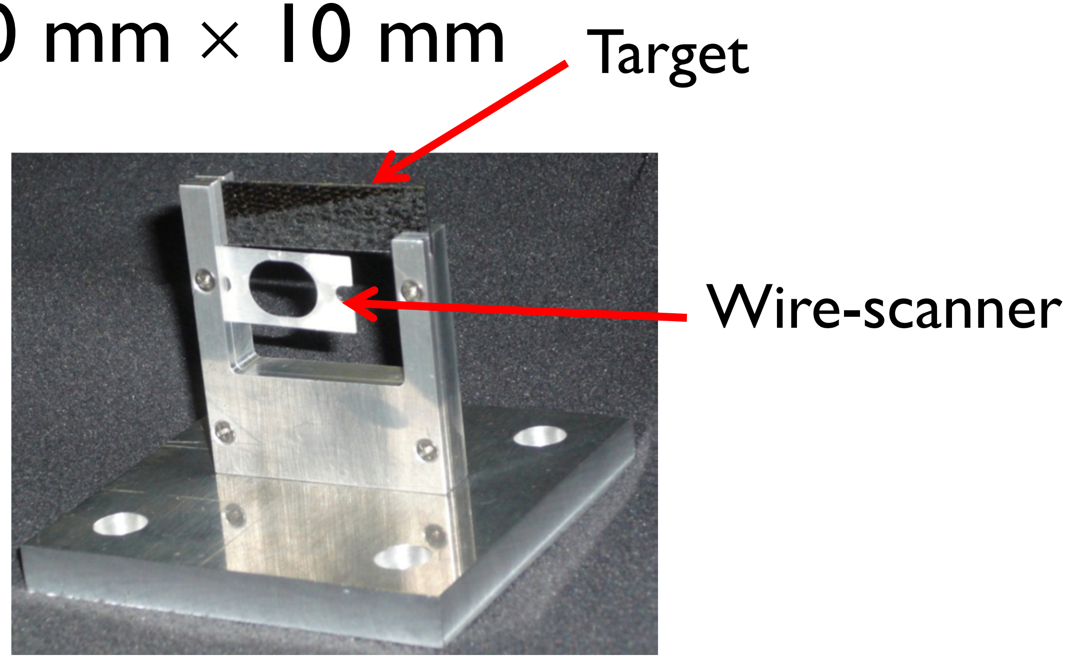
Different transverse beam sizes were used



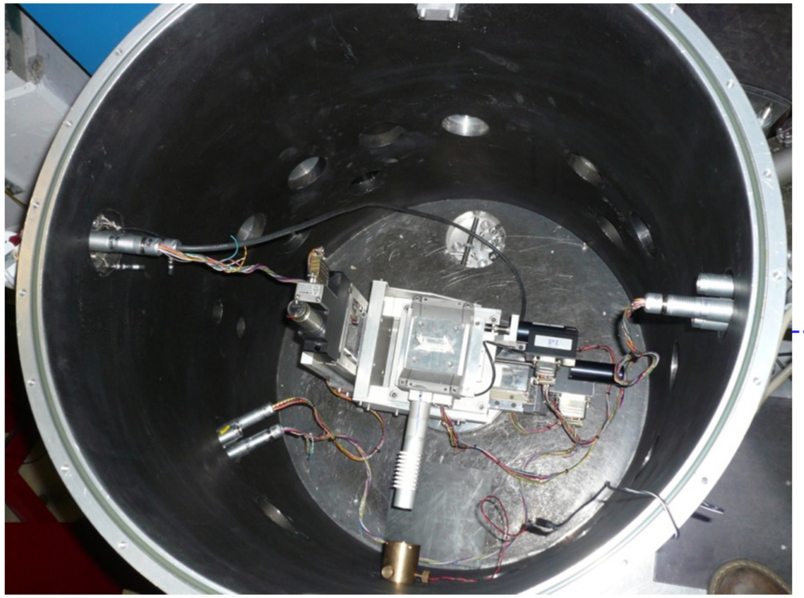
BTR Target

- The BTR target was made of a 50 nm thin molybdenum layer (surface roughness better than 0.5 nm), evaporated onto a 0.5 mm thick silicon substrate. Target dimensions 40 mm × 10 mm



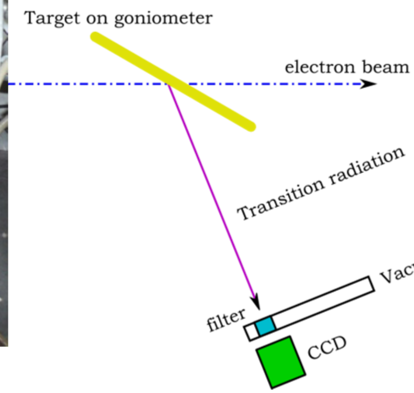


- The target and the wire-scanner were setup on the goniometer. Two grazing angles α were used: α=28.07 deg (“forward geometry”) and α = 67.5 deg (“backward geometry”)

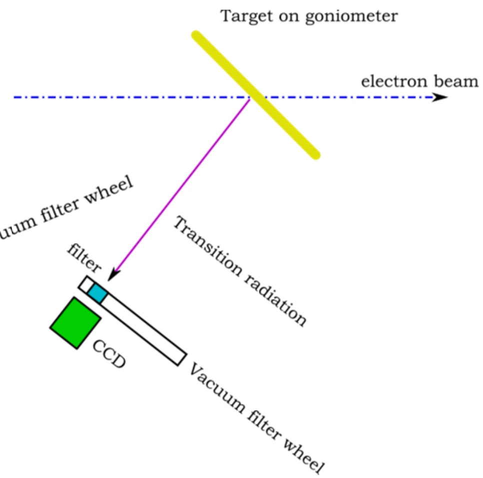


The goniometer in the vacuum chamber

α=28.07 deg

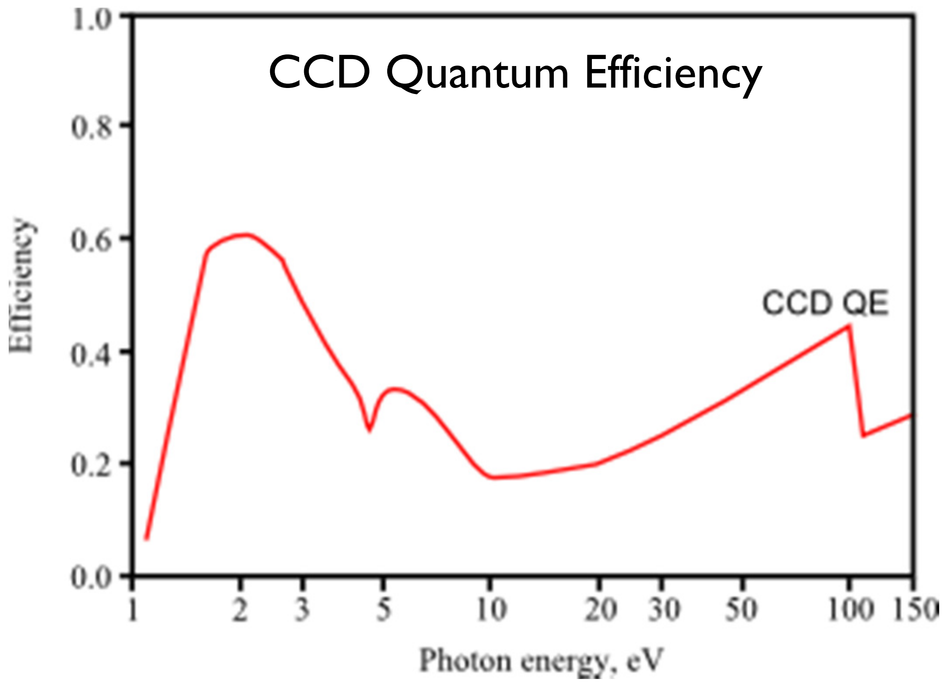


α = 67.5 deg

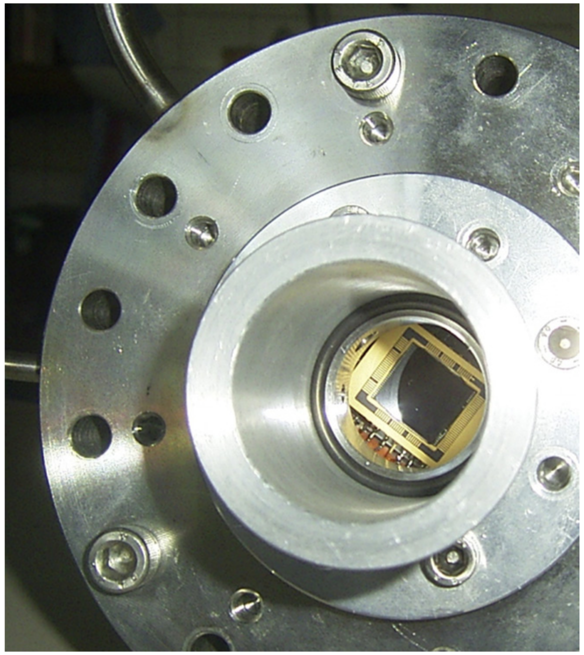


CCD-camera

- We used scientific grade CCD camera (ANDOR DO434-BN-932) with 1024×1024 pixels and a pixel size was 13×13 um^2. CCD was cooled down to -40 C

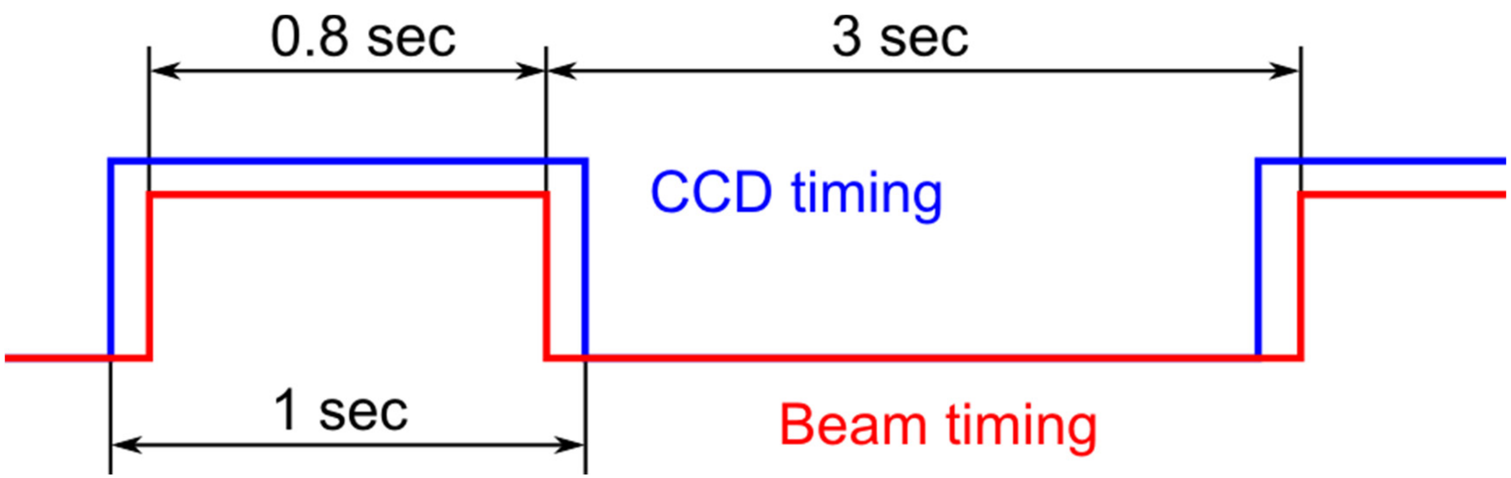


CCD Chip



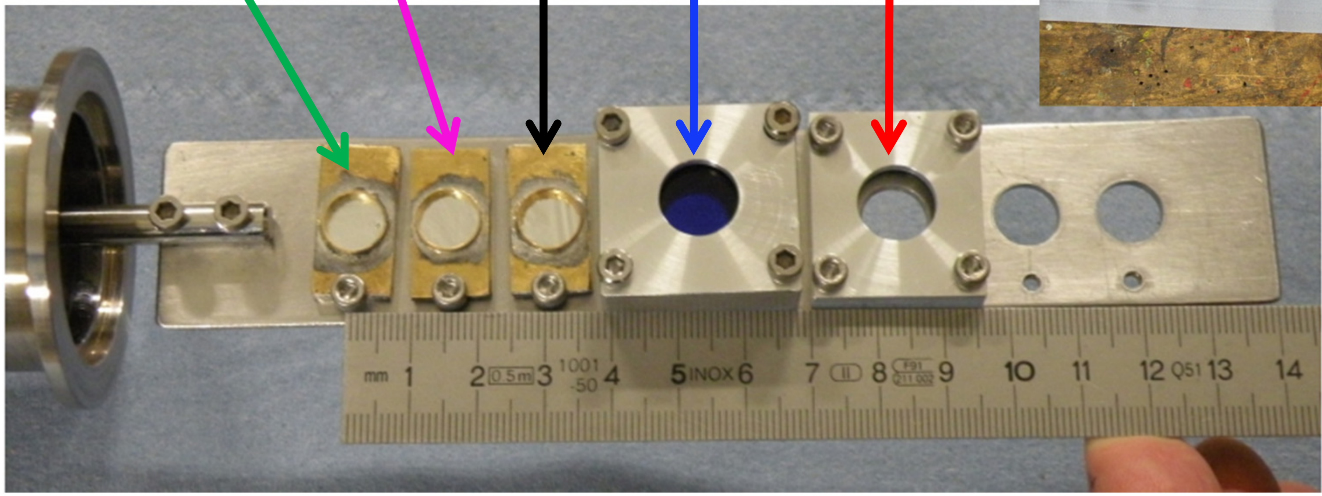
Light collection

- The camera collected light during 1 sec: 0.1 sec before start of the macro pulse, 0.8 sec during macro pulse duration, and 0.1 sec after the macro pulse.

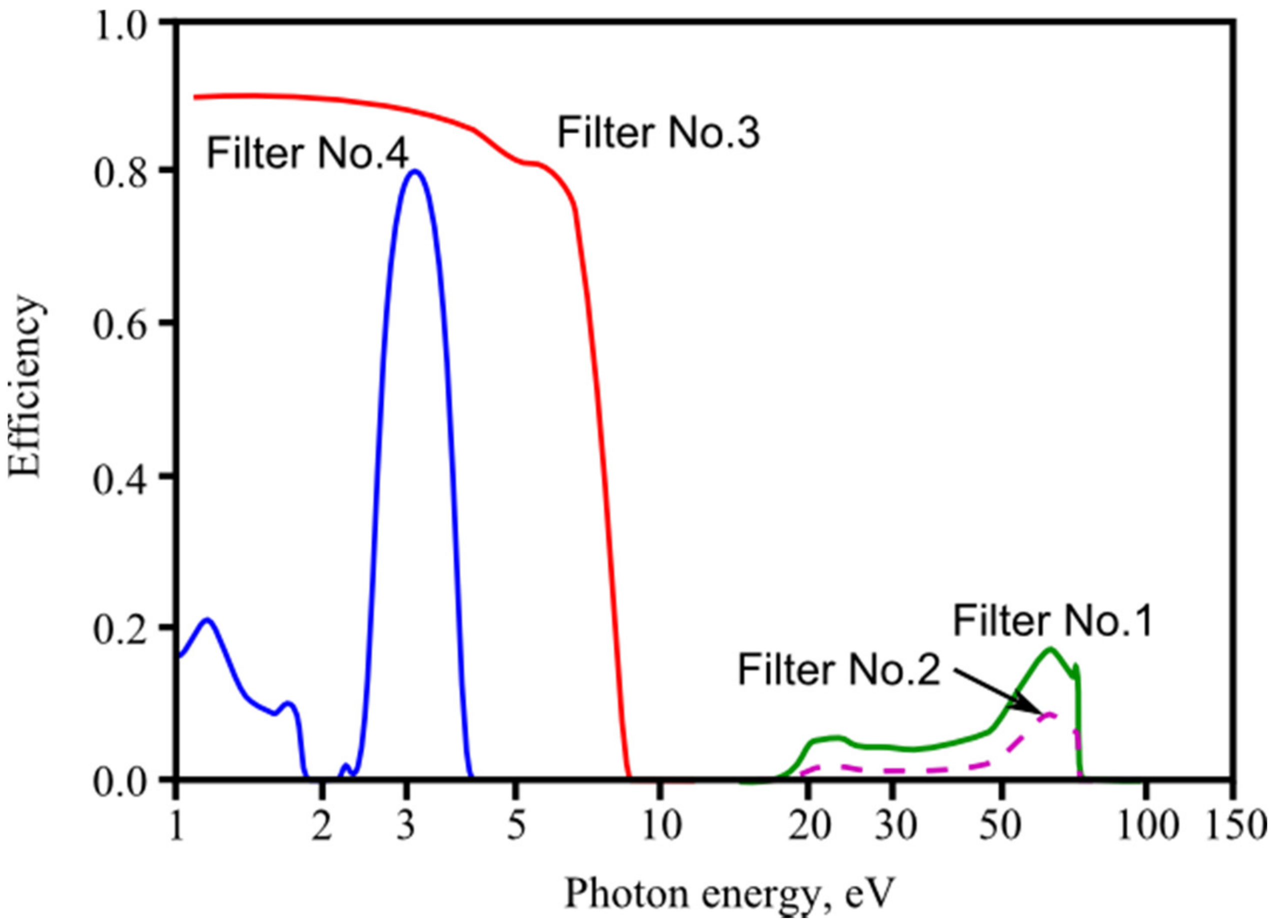


Filters

- Different filters on the movable filter holder were used during the experiment.



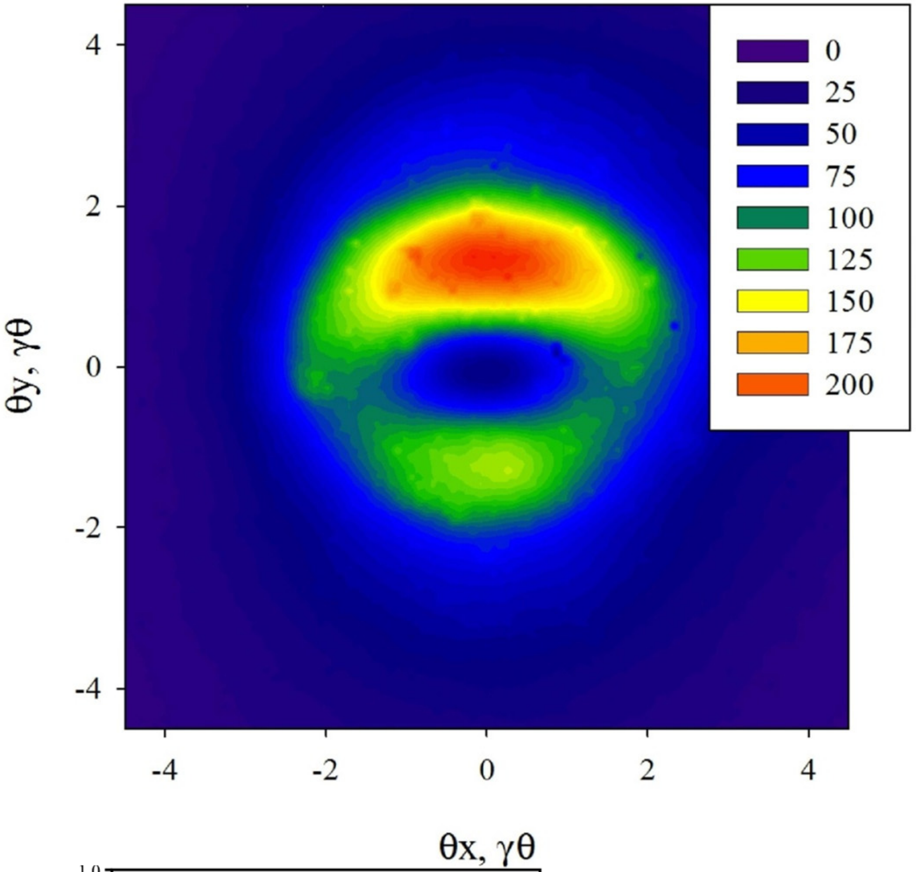
Filter efficiency

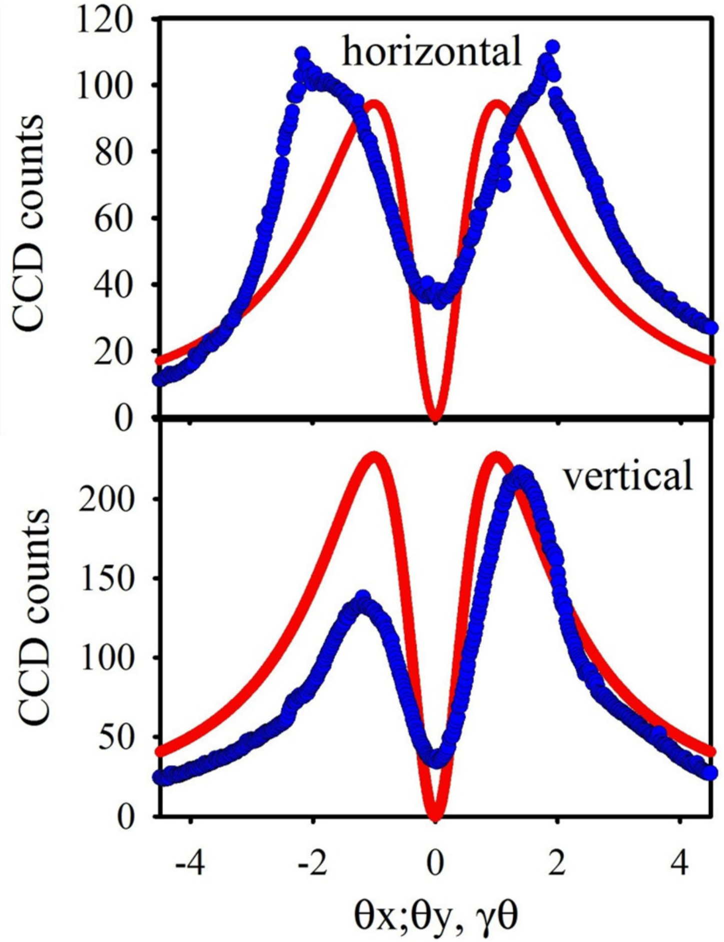


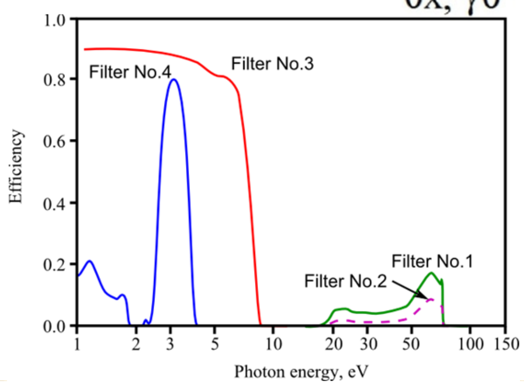
EXPERIMENTAL RESULTS

- Both theoretical and experimental results presented in this section were calculated resp. normalized for a total number of electrons of $N_e=10^{10}$ (usual bunch population of modern accelerators).
- Results are presented in the unit CCD counts per pixel

α=28.07, OTR, FilterNo.3, FS

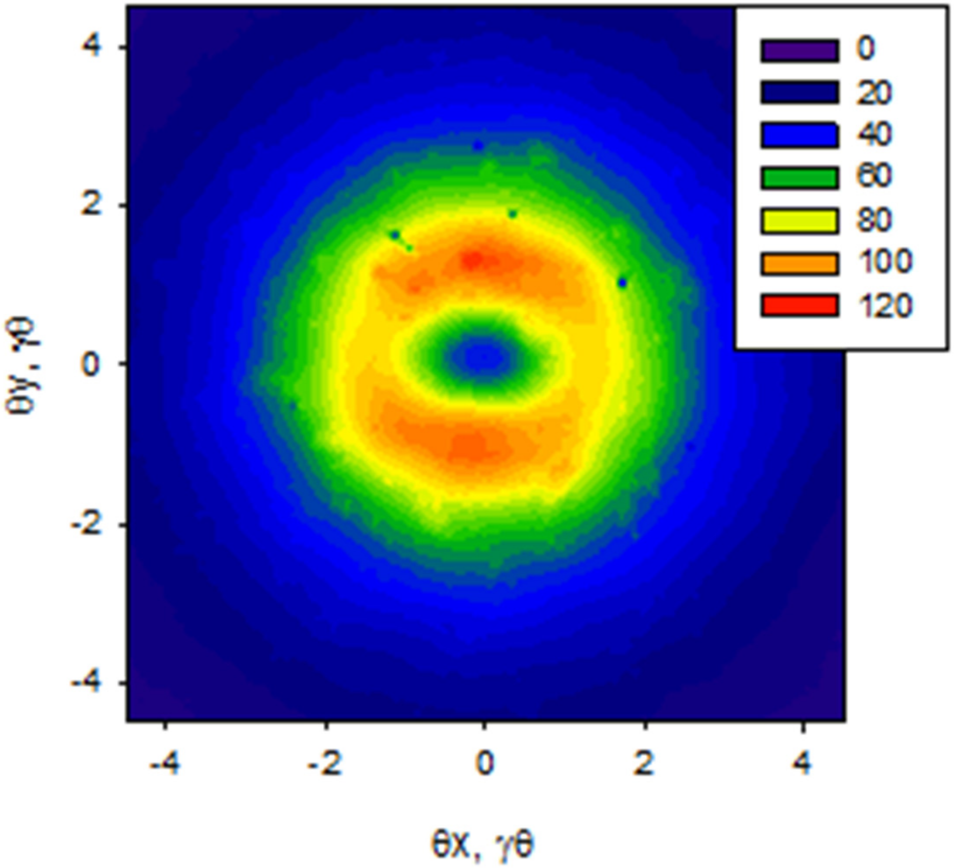






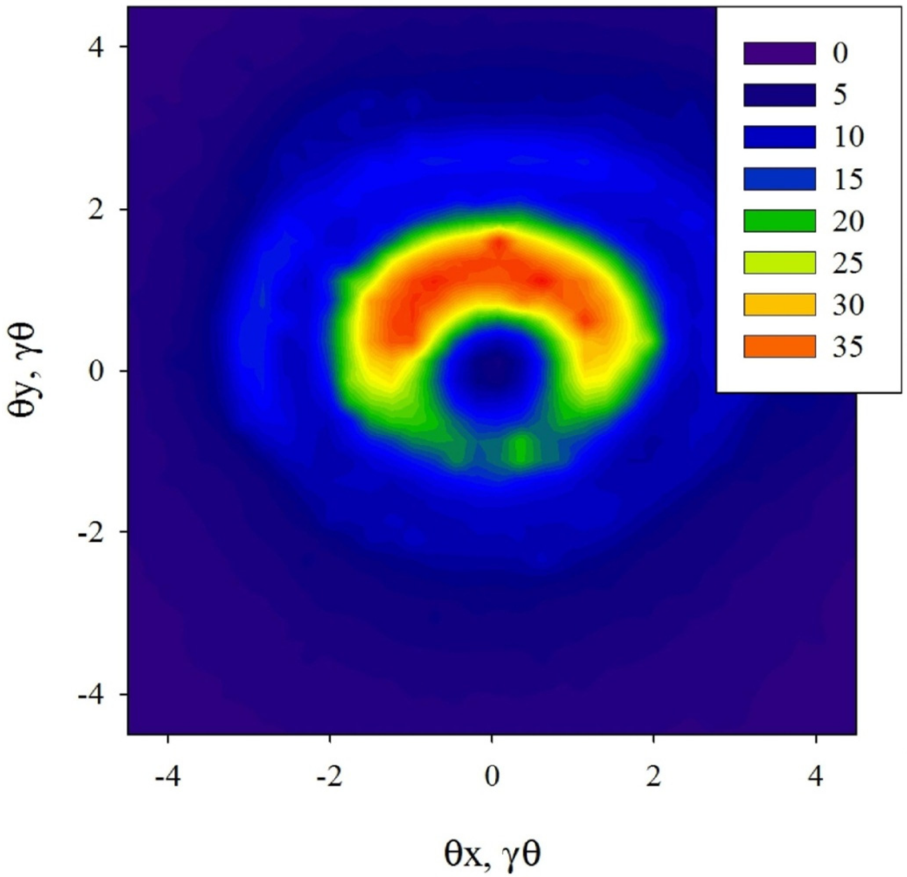
Theoretical curves are divided by factor of 2

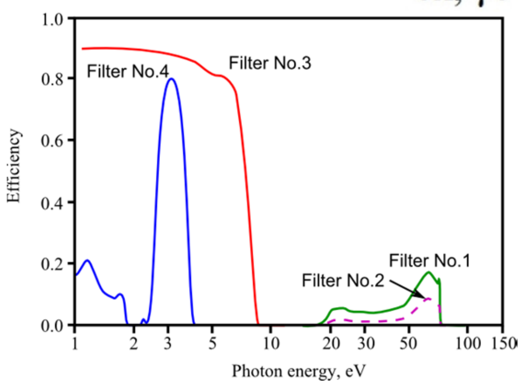
α=67.5, OTR, Filter No.3, FS

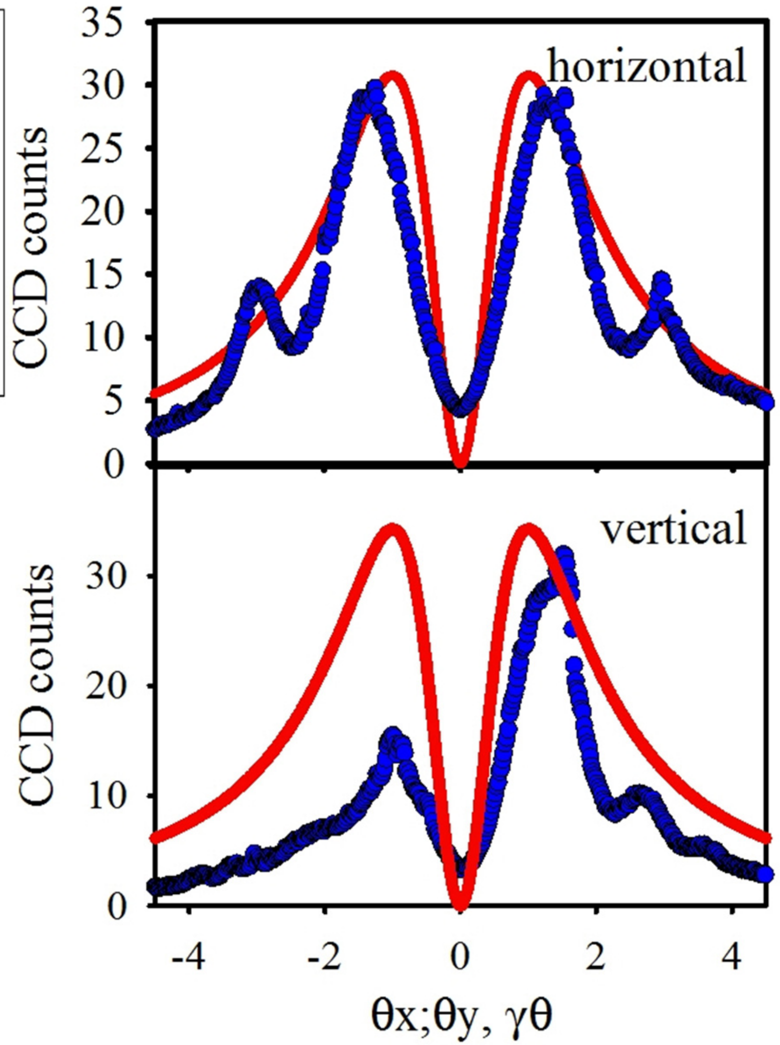


The distribution is symmetrical when all quads are off.
The asymmetry comes from quad synchrotron radiation.

α=67.5, OTR, Filter No.4, Blue

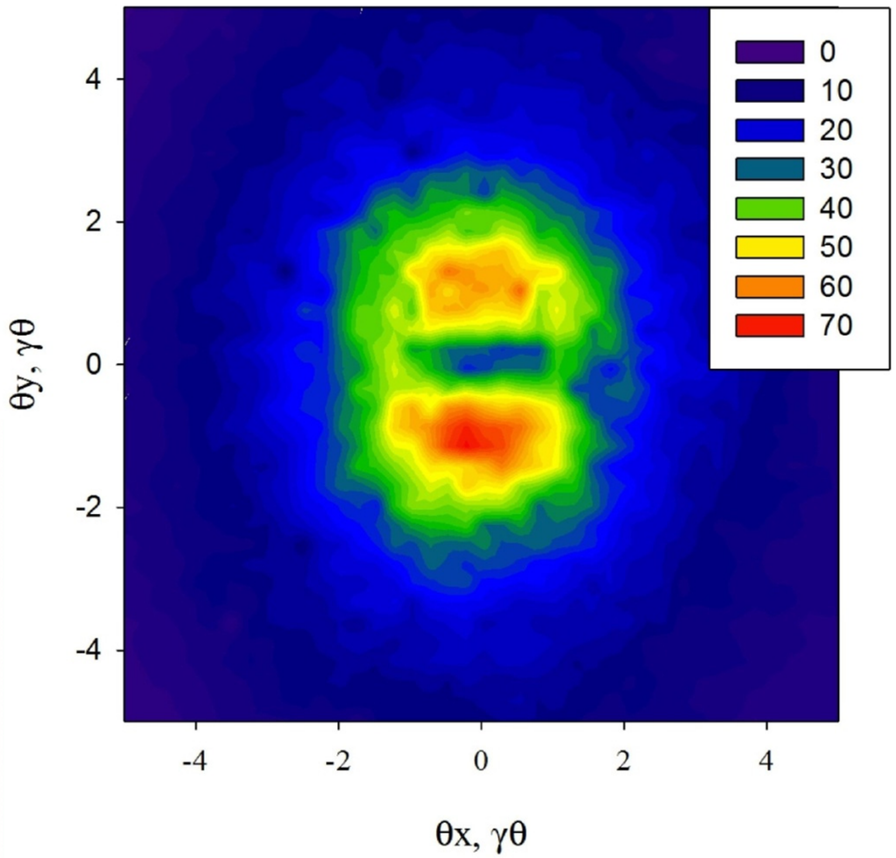


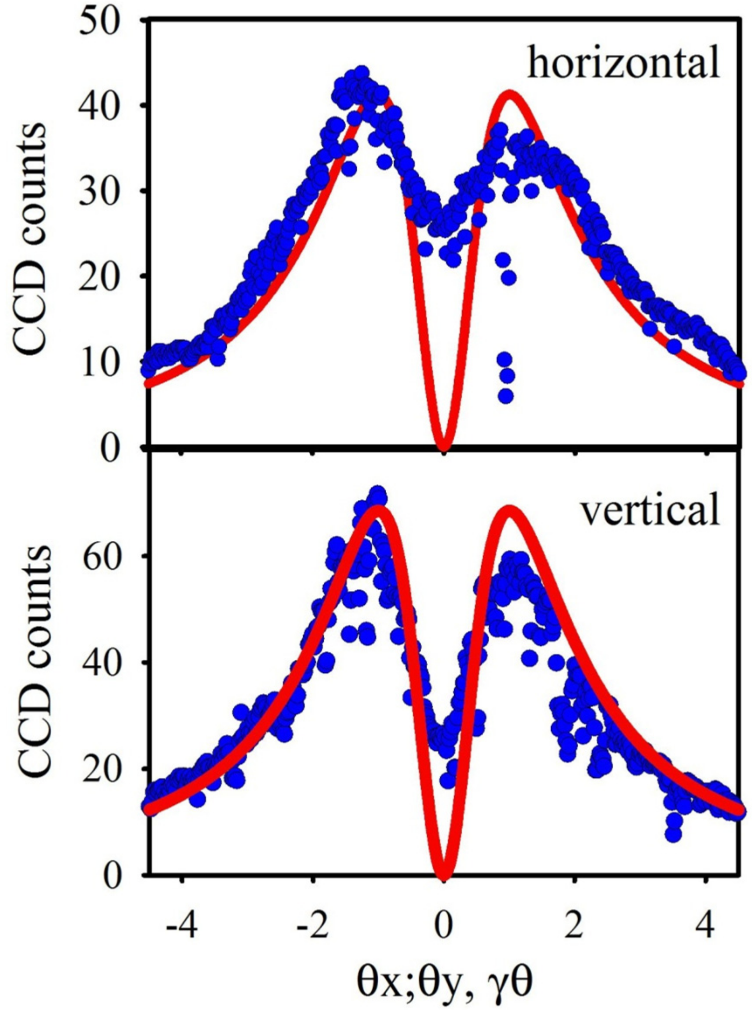


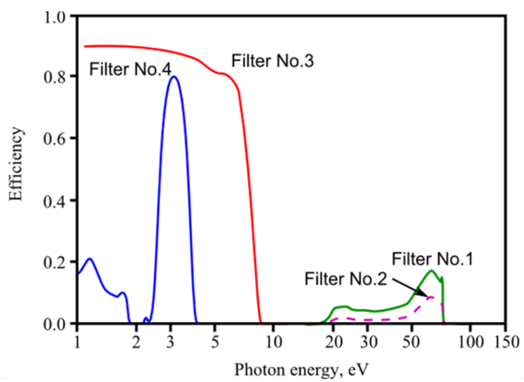


Theoretical curves are divided by factor of 2

α=28.07. OTR. Filter No.1, Al foil

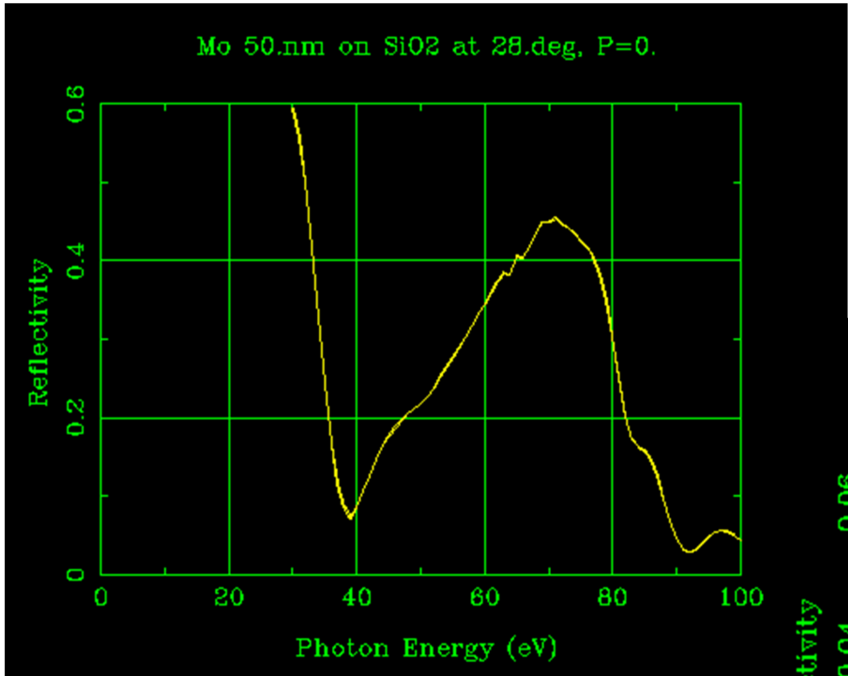


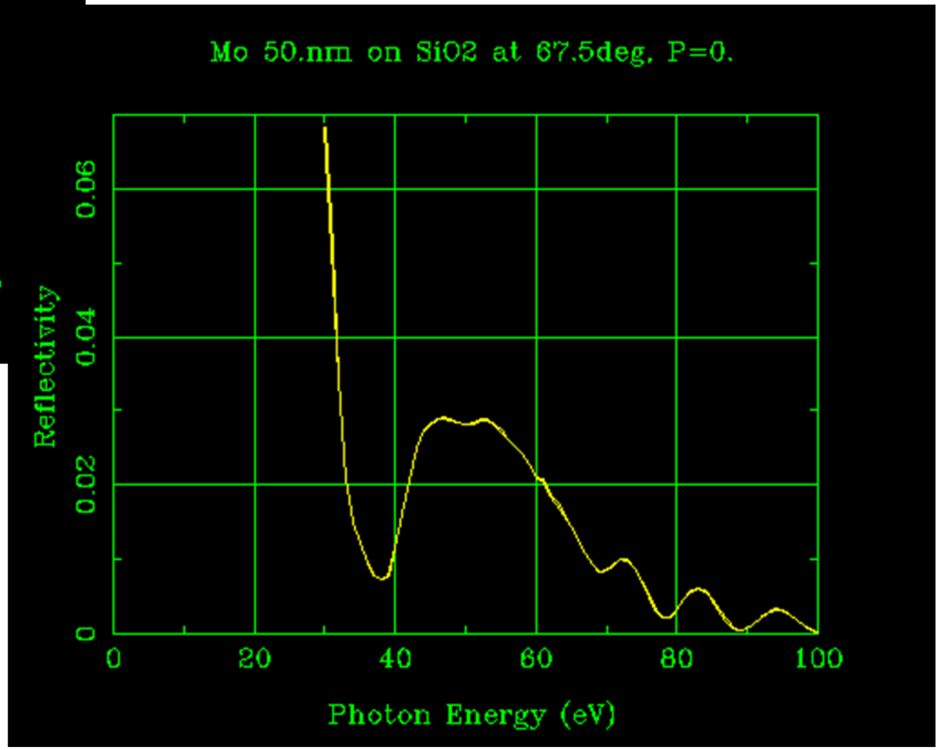




Theoretical curves are multiplied
by factor of 6

Molybdenum reflection coefficients

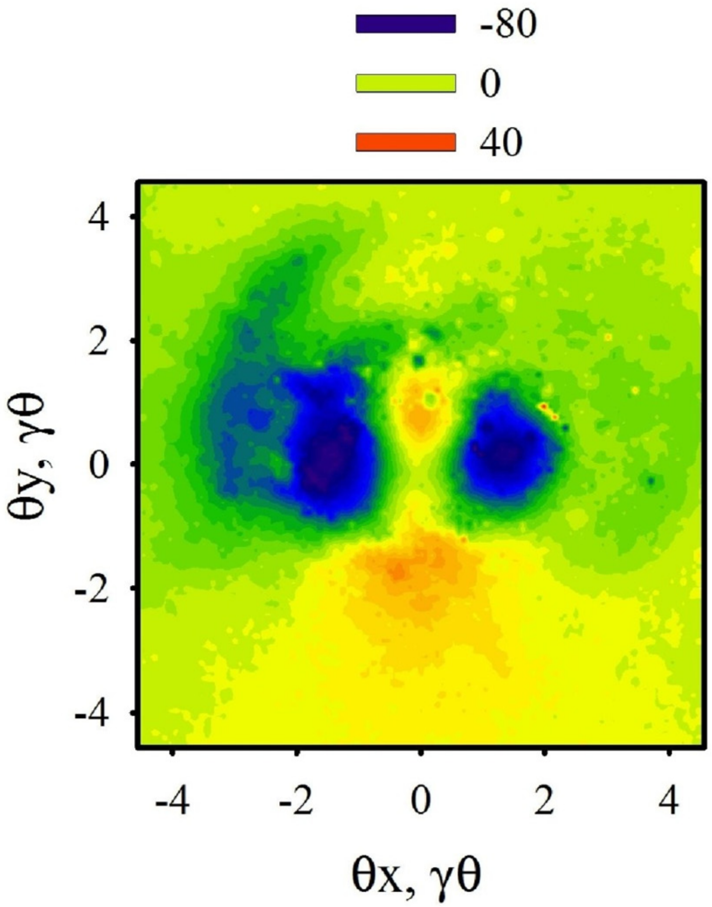




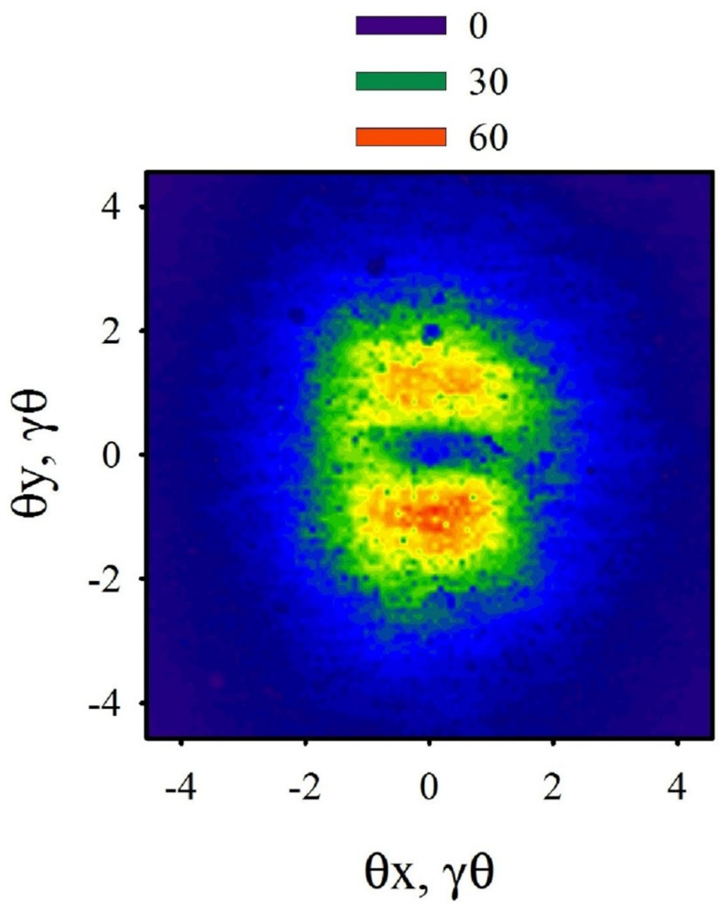
Henke, B. L., Gullikson, E. M. and Davis, J. C., Atomic Data and Nuclear Data Tables **54**(2), 181-342 (1993).
http://henke.lbl.gov/optical_constants/

“Forward” minus “backward”

Optical Radiation



EUV Radiation



Radiation intensity

Experimental radiation yield is given for different beam profiles.

		EUV Radiation, Filter No.1, Al	Optical Radiation, Filter No.4, Blue	Optical Radiation, Filter No.3, FS
Forward	Experiment	$(2.4\ldots3.6)\times10^6$	$(1\ldots1.2)\times10^6$	$(7.1\ldots8.9)\times10^6$
	Theory	0.58×10^6	4×10^6	20×10^6
	Ratio E/T	4.1…6.2	0.25…0.3	0.36…0.45
Backward	Experiment	$(0.4\ldots0.45)\times10^6$	$(1\ldots1.44)\times10^6$	$(6.9\ldots10)\times10^6$
	Theory	0.06×10^6	4.1×10^6	21×10^6
	Ratio E/T	6.7…7.5	0.24…0.35	0.33…0.48

Conclusion

- The EUV radiation is clearly and reproducible observed.
- The intensity of the measured EUV radiation was higher than predicted from the model and higher than OTR intensity with bandpass filter,
- Application as basis for transverse beam profile diagnostics seems to be realistic.
- EUV imaging experiment is planned this year.

THANK YOU FOR YOUR ATTENTION!