Investigation of Cherenkov Radiation Characteristics from 855 Mev Electron Beam

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Abstract

Radiation based beam diagnostics is a versatile tool, especially for transverse beam profile measurements. While the use of Optical Transition Radiation (OTR) has long history since developed, the application of Cherenkov Radiation (ChR) having comparatively higher intensity and tunable frequency spectrum just arouse interest. In order to investigate the ChR properties, an experiment has been carried out at the $855\,MeV$ electron beam of the Mainz Microtron MAMI (University of Mainz, Germany). The beam size was $536\,\mu m$ in horizontal and $6.3\,\mu m$ in vertical direction measured with a scintillator and the same optical scheme. A $200\,\mu m$ thick fused silica was used as radiator. The beam images were recorded with a standard CMOS camera and an objective lens. While the detector was at a fixed observation angle (much larger than $46.77°$ - the Cherenkov angle for a fused silica), the radiator could be rotated with respect to the beam direction such that the ChR angular distribution was measured as a function of the radiator orientation. This report gives an overview of the experiment together with measurements and first theoretical comparisons.

Theoretical model

The ChR radiation characteristics from dielectric plate may be calculated by the Pafomov's formula [1], but the equation is the way to complicated. In the works [2, 3] there was developed another approach. For the case $\lambda \ll a, b$ ($a,\ b$ – transverse radiator sizes) the approach gives:

$$\begin{aligned}\frac{d^2W}{\hbar\, d\omega d\Omega} = \frac{e^2}{\pi^2 c}\frac{\beta_z^2\cos^2\theta}{\left((1-\beta_y n_y)^2-\beta_z^2\cos^2\theta\right)^2}\left|\frac{\varepsilon-1}{\varepsilon}\right|^2\left|\frac{1-\exp\left\{-\frac{i\omega L(1-\beta_z Z-n_y\beta_y)}{\beta_z c}\right\}}{1-\beta_z Z-n_y\beta_y}\right|^2\times \\ +\left(\beta_y^2\beta_z^2\sin^2\varphi\times(|Z|^2+\sin^2\theta)\left|\frac{\sqrt{\varepsilon}}{\cos\theta+Z}\right|^2+\right. \\ \left.\left|\frac{\varepsilon}{\varepsilon\cos\theta+Z}\right|^2\left|(\beta_z^2+n_y\beta_y+\beta_z Z-1)\sin\theta-\beta_y\beta_z\cos\varphi\, Z\right|^2\right),\end{aligned} \tag{1}$$

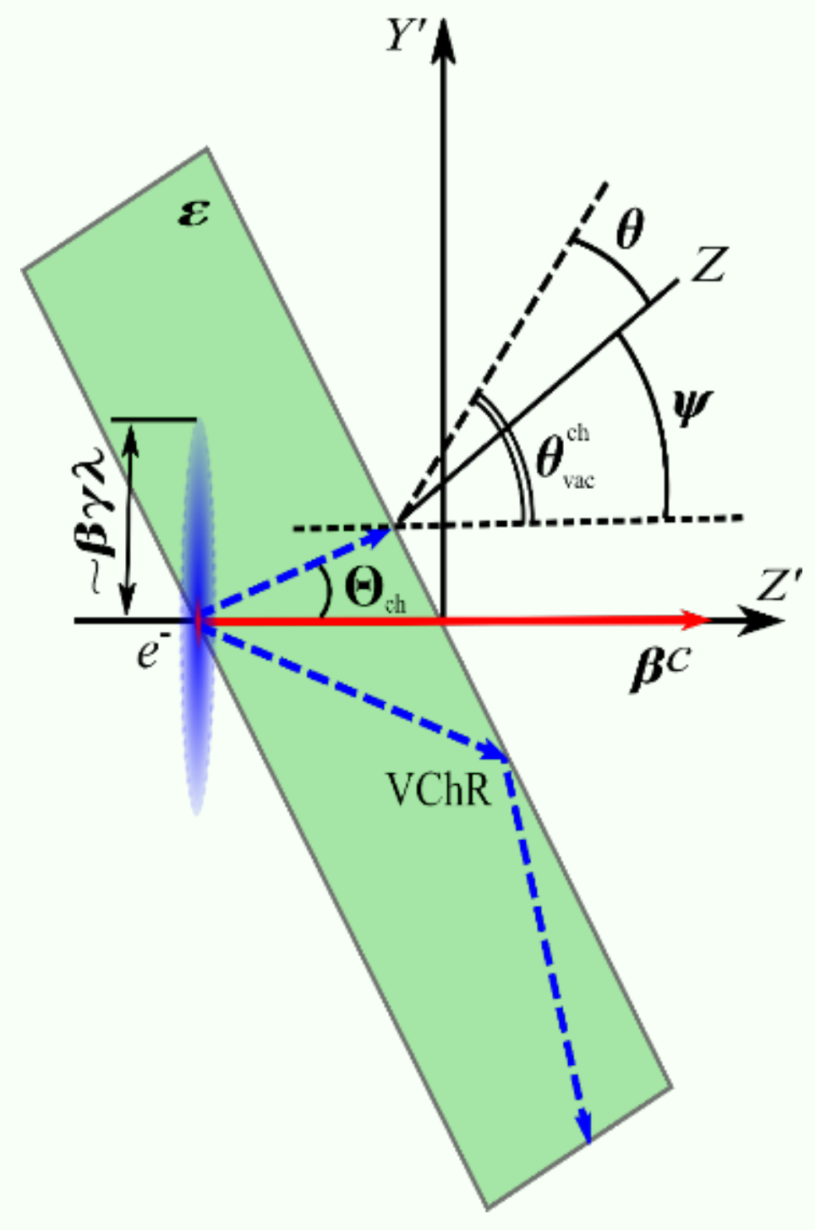

Figure 1: Geometry of ChR process and the angular variables

Here the variables $\theta, \varphi, n_{x,y,z}$are determined in the frame connected with the boundary normal (see Figure 1):

$$Z = \sqrt{\varepsilon - \sin^2\theta};$$
$$\beta_y = -\beta\sin\psi;\quad \beta_z = -\beta\cos\psi;$$
$$n_z = \cos\theta;$$
$$n_x = \sin\theta\sin\varphi;\quad n_y = \sin\theta\cos\varphi,$$

and $\varepsilon(\lambda) = n^2(\lambda)$ is the permitivity. In the conventional coordinate frame connected eith the electron beam all the angular variables are determined by the equations:

$$\cos\theta_{vac} = \cos\theta\cos\psi - \sin\theta\cos\varphi\sin\psi;$$
$$\tan\varphi_{vac} = \frac{\sin\theta\sin\varphi}{\sin\theta\cos\varphi\cos\psi + \cos\theta\sin\psi}.$$

Experimental Setup

Here are OTR (Figure 2) and ChR (Figure 3) experiments schemes are shown.

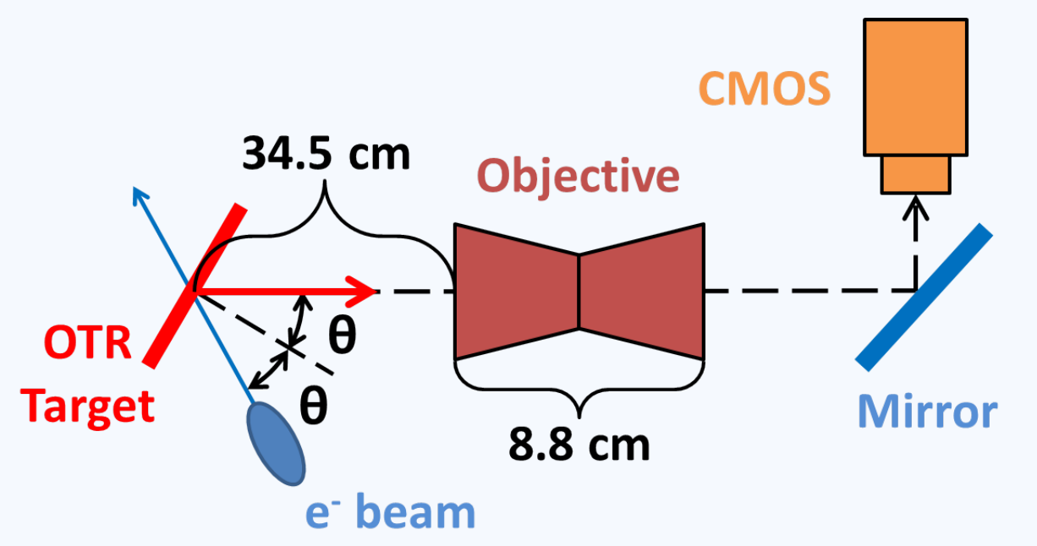

Figure 2: OTR experiment.

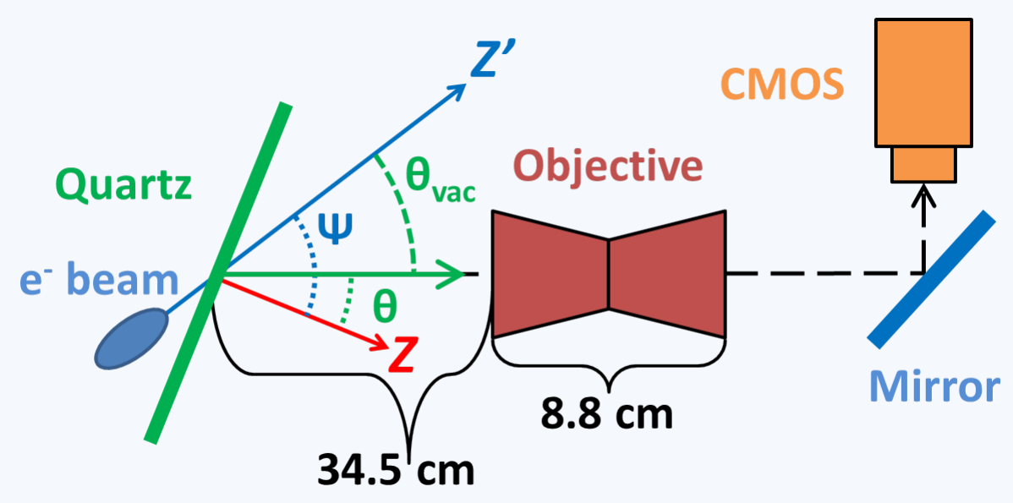

Figure 3: ChR experiment.

- $E = 855\,MeV$
- $\sigma_x \times \sigma_y = 536 \times 6.3\,\mu m$ (scintillator result).
- the angle for OTR case was $\theta = 22.5°$.
- in the case of ChR the crystal could be rotated in order to get the best condition.
- The objective - *Schneider-Kreuznach Makro Symmar 5.6/180* ($F = 180\,mm$).
- The CMOS camera - *Basler aca2440-20gm*.
- OTR experiment had also bandwidth filter inserted 500, 550 or $650\,nm$.

The angles in Figure 3 are related according to the following expression [4]:

$$\theta_{vac} = \Psi - \arcsin\left[n\cos\left(\Theta_{ch} + (\pi/2 - \Psi)\right)\right] \tag{2}$$

The beam size was measured by a scintillator (*GAGG*). The result is $\sigma_x \times \sigma_y = 536 \times 6.3\,\mu m$. The result is in Figure 4.

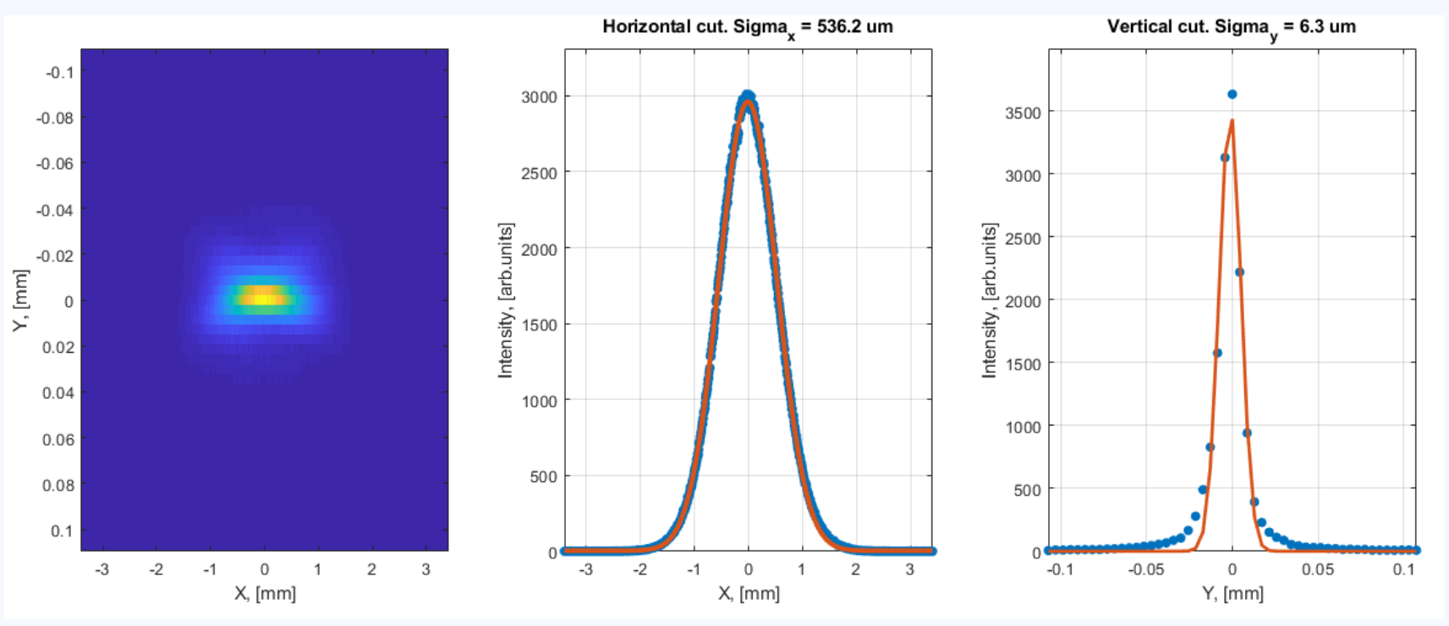

Figure 4: GAGG measurement result.

Experiment results

The OTR measurement result one may see in Figure 5. The measured sizes are $\boldsymbol{\sigma_x \times \sigma_y = 631 \times 8.9\,\mu m}$. In the measurement the $550\,nm$ filter has been used.

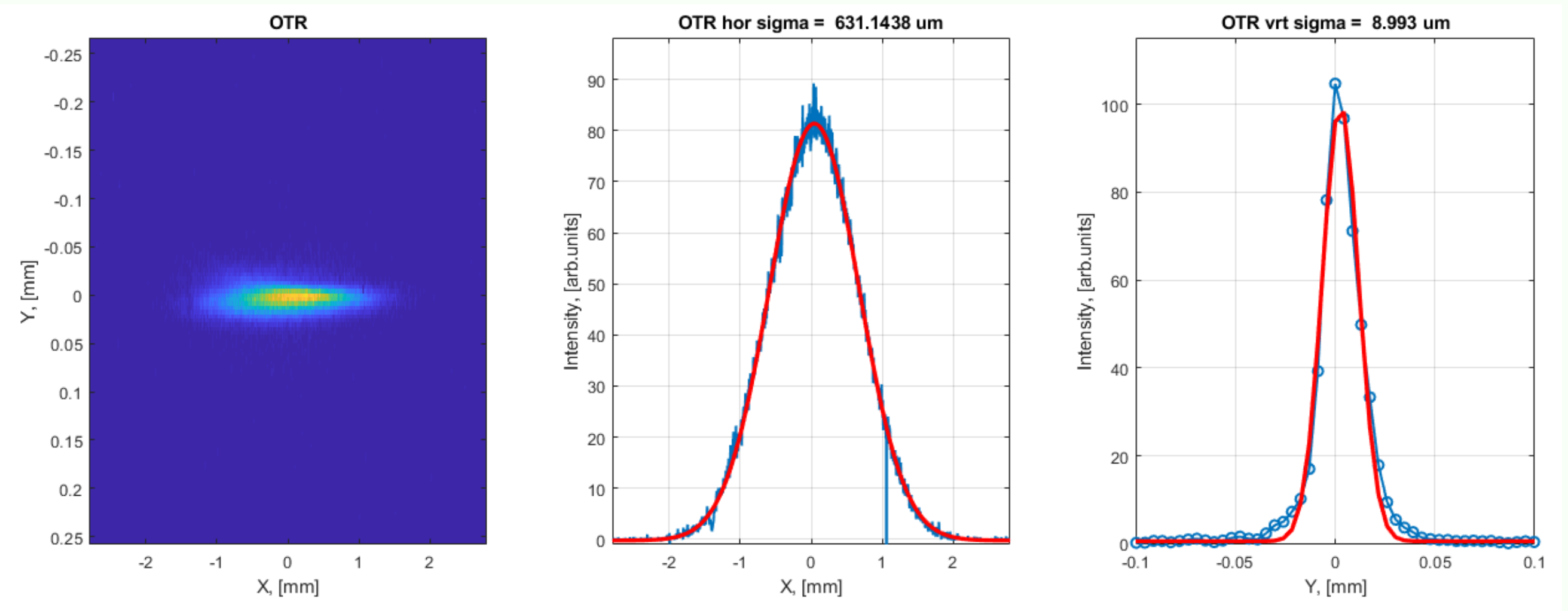

Figure 5: OTR measurement result.

The resulting ChR picture is shown in Figure 6. The beam size is $\boldsymbol{\sigma_x \times \sigma_y = 661 \times 8.1\,\mu m}$. The crystal angle was $\Psi = 28°$ in the measurement.

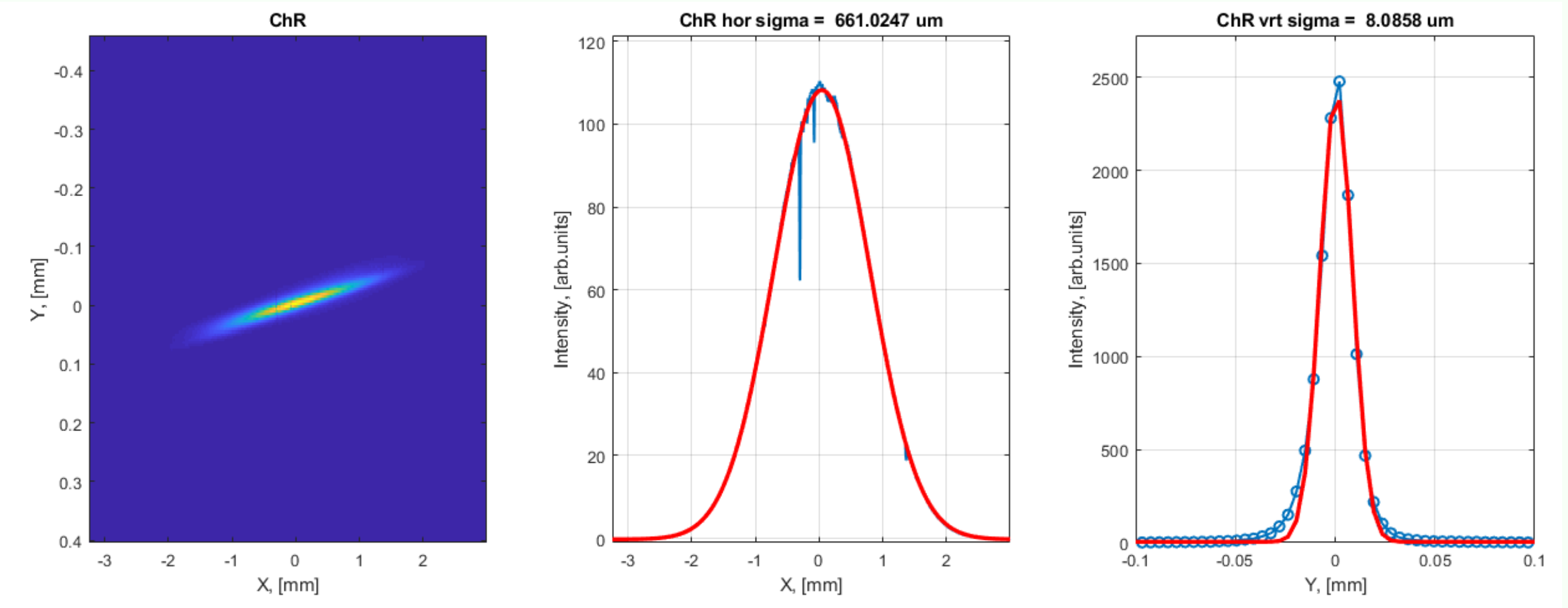

Figure 6: ChR measurement result.

Simulation

Using Eq. 1 ChR fields were simulated on the objective (see Figure 7). One may see that the part of the whole Cherenkov cone (vertical line) is captured by the lens. Then the PSF distributions for both directions were simulated on the image plane using conventional Fourier transform (see Figure 8).

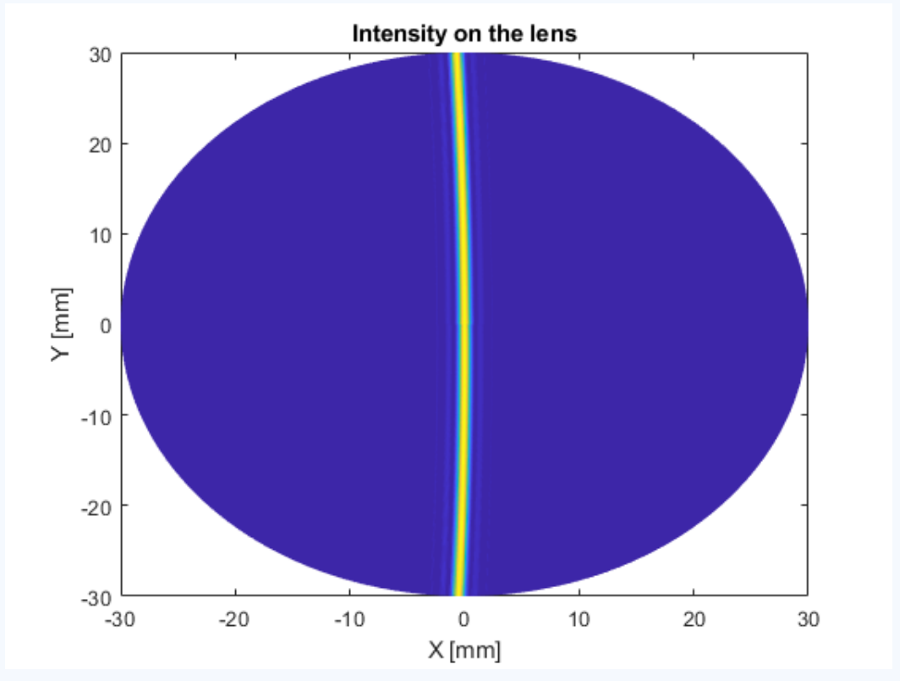

Figure 7: PSF on the lens.

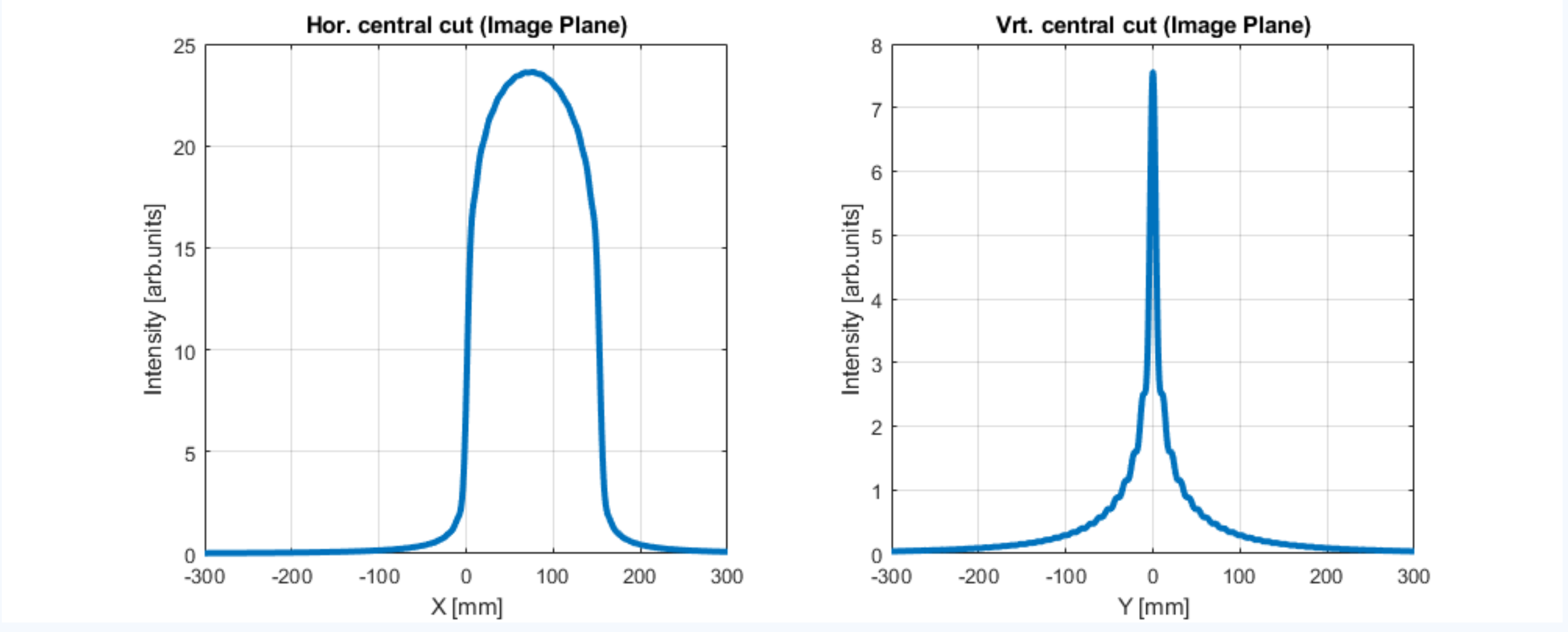

Figure 8: PSF in the image plane

Results

- We demonstrated the possibility to measure a beam profile utilizing optical Cherenkov Radiation.
- The results of the beam profile measurements were compared to the conventional OTR technique ones.
- We observed some broadening of the beam profile measured by both OTR and ChR techniques due to the non-ideal focusing of the optical scheme.
- The theory model allowing to calculate ChR PSF is developed.

References

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[4] E.Kh. Baksht, A.V. Vukolov, et al., "Cherenkov Radiation in the visible and Ultraviolet Spectral Ranges from 6-MeV Electrons Passing through a Quartz Plate", Optics and Laser Physics, 109, N. 9 (2019) 584-588.

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