Structured light from helical undulators

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The 9th Asian Forum for Accelerators and Detectors
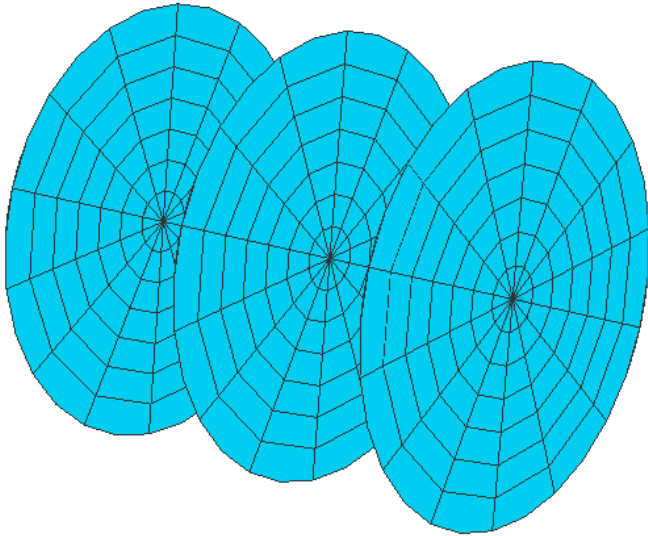
2018/0131

Introduction

- Structured light means light which have spatially controlled intensity, polarization and (or) phase distribution.

- Spatially uniform polarization state with left-handed or right-handed spiral phase front called optical vortex.
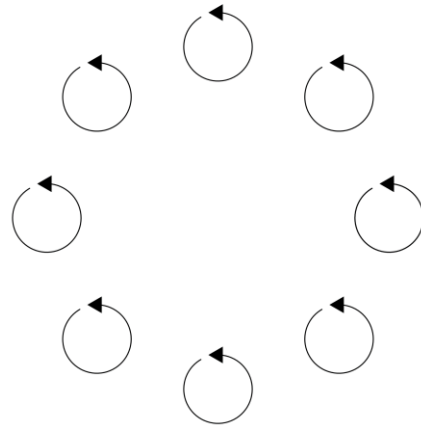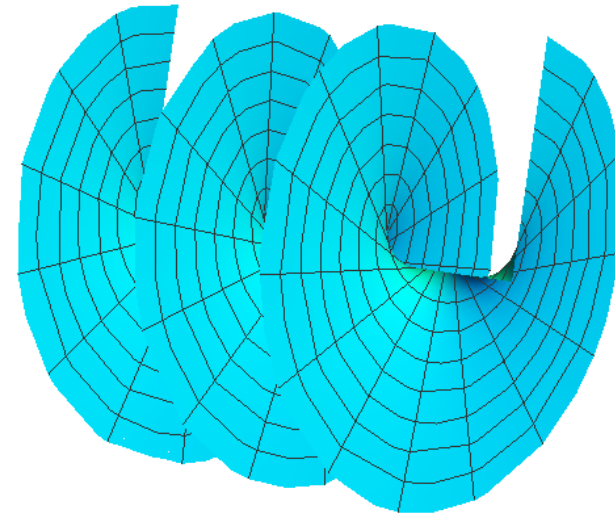
Optical vortex

Normal beam

equiphasic surface
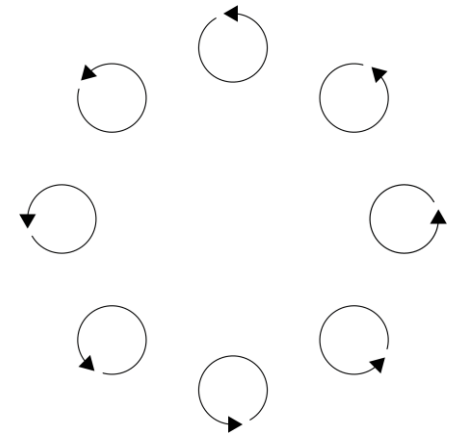
Phase condition
on a vertical plane

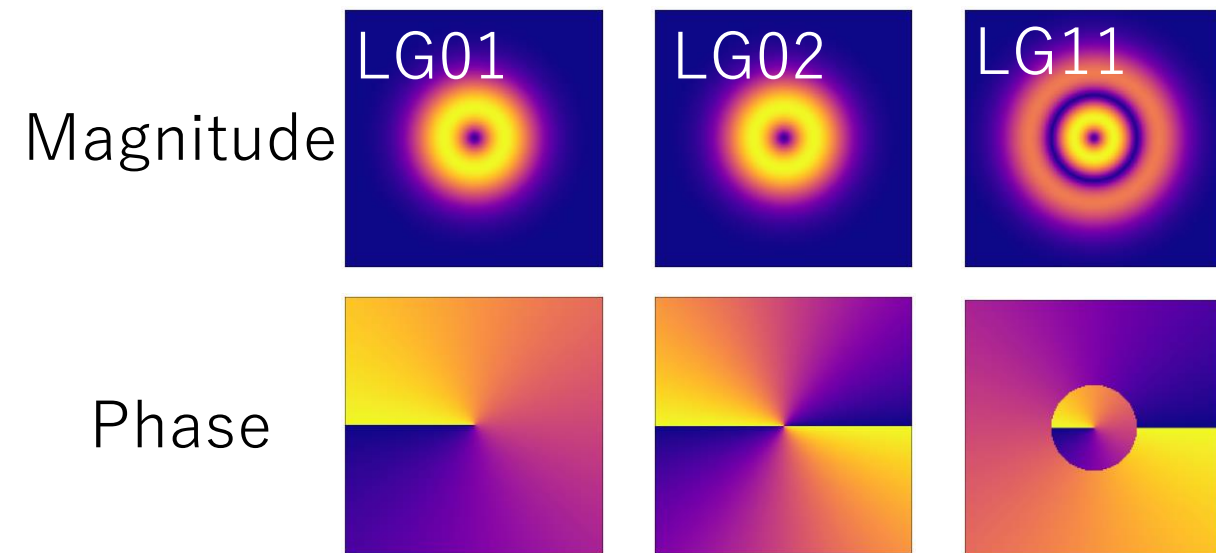### Optical Vortex

equiphasic surface

Phase condition
on a vertical plane

Laguerre-Gauss mode

$$\text{L}G_{pl}(r,\phi) = \sqrt{\frac{2p!}{\pi(p+|l|)!}}\frac{1}{w(z)}\left[\frac{r\sqrt{2}}{w(z)}\right]^{|l|}\exp\left[\frac{-r^2}{w^2(z)}\right]L_p^{|l|}\left(\frac{2r^2}{w^2(z)}\right)\boxed{\exp[il\phi]}$$

$$\exp\left[\frac{ik_0r^2z}{2(z^2+z_R^2)}\right]\exp\left[-i(2p+|l|+1)\tan^{-1}\left(\frac{z}{z_R}\right)\right]$$

LG01   LG02   LG11

Magnitude

Phase

- Optical vortex carries $l\hbar$ of orbital angular momentum per photon other than spin angular moment which originate from right or left circular polarization.

L. Allen, et. al. PRA 45 8185-8189 (1992).
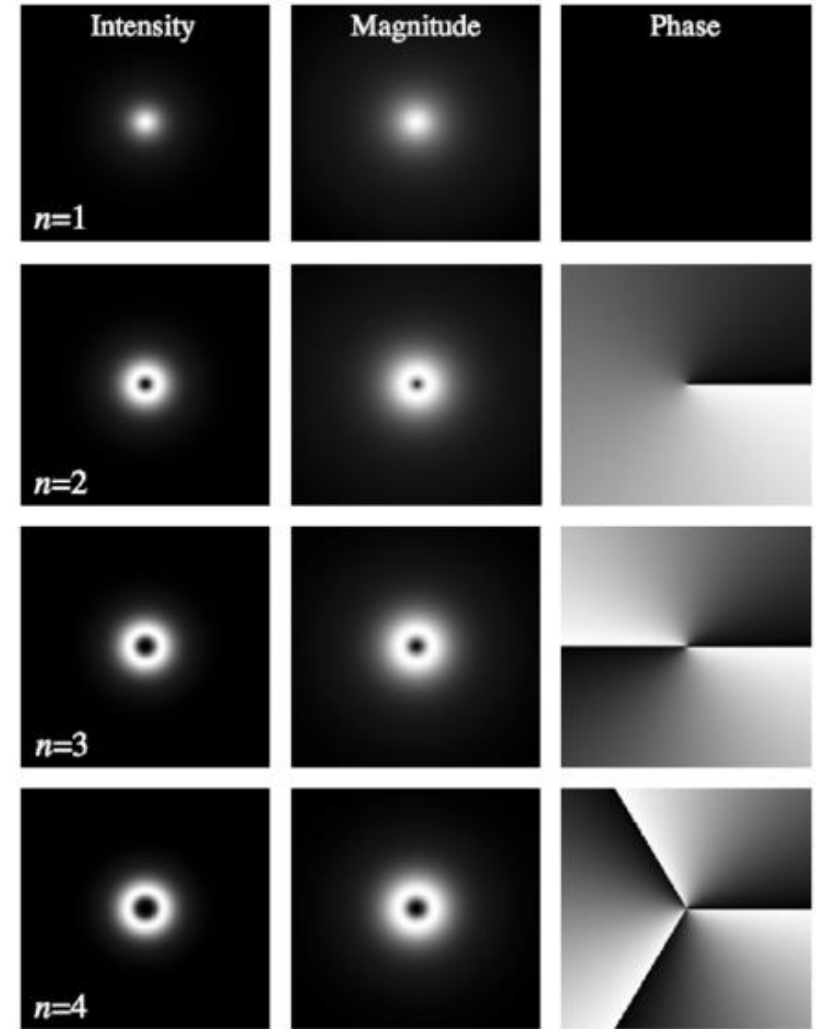
4

Higher harmonics from helical undulators

- Higher harmonics from helical undulators become optical vortex.

$$\frac{d^2I}{d\omega d\Omega} = \frac{e^2\gamma^2 n^2 \xi^2}{4\pi\epsilon_0 c}\left[|A_x|^2 + |A_y|^2\right] L\left(\frac{N\Delta\omega}{\omega}\right)$$
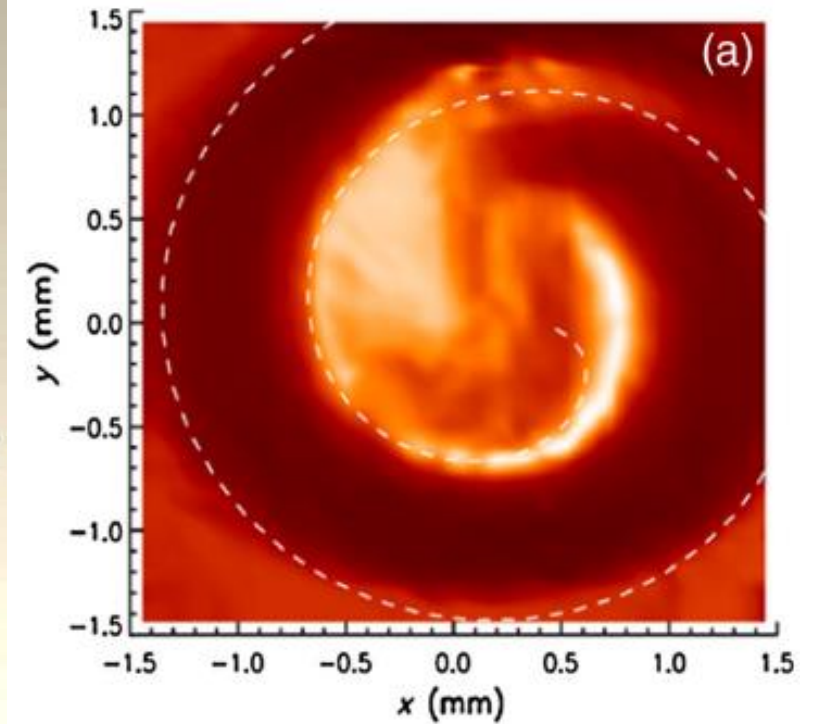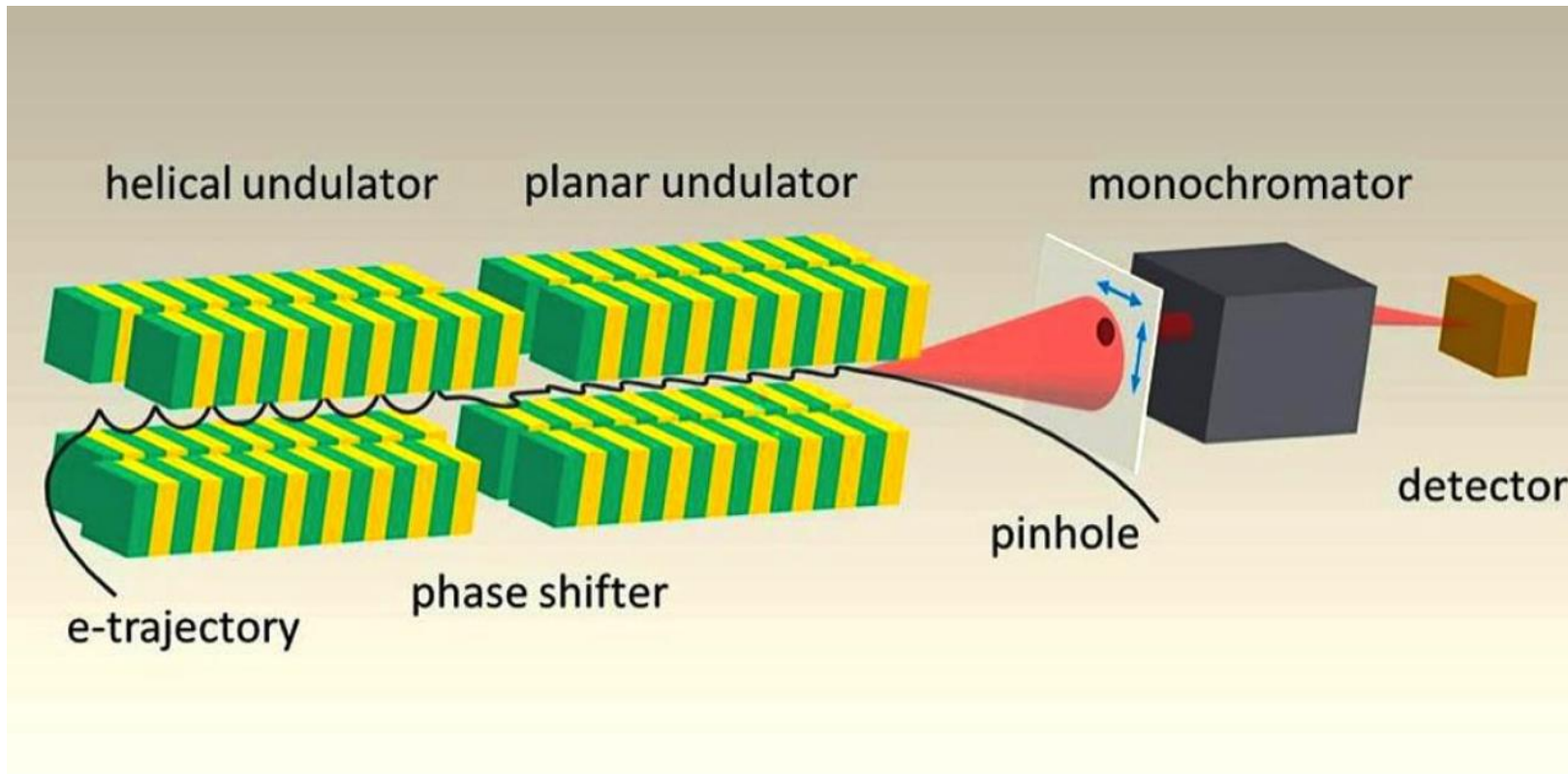
Intensity distribution equation for APPLE undulator

$$A\,(\gamma\theta, \phi) = (A_x - iA_y)/\sqrt{2}$$

$$= \sqrt{2}\exp[i(n-1)\phi]\left[\left(\gamma\theta - \frac{nK}{X}\right)J_n(X) - KJ_n'(X)\right]$$

Shigemi Sasaki and Ian McNulty
PRL 100, 124801 (2008)

Intensity	Magnitude	Phase
n=1		
n=2		
n=3		
n=4		

First Experimental Demonstration

Interference pattern from tandem undulator at photon energies of 99 eV
BESSY II Storage ring   E = 917 MeV

J.Bahrdt, et. al. PRL 111, 034801 (2013).
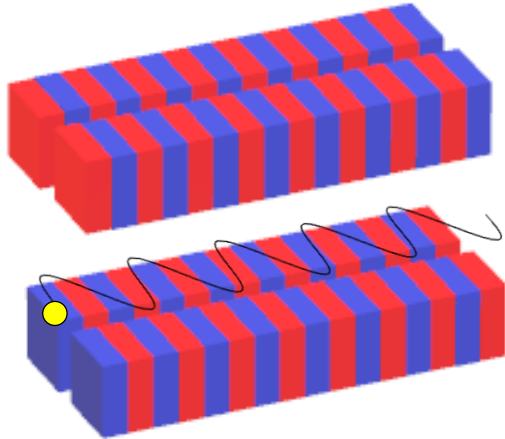
Experiment at UVSOR-III storage-ring

E ：500 MeV
ε ：8 nmrad
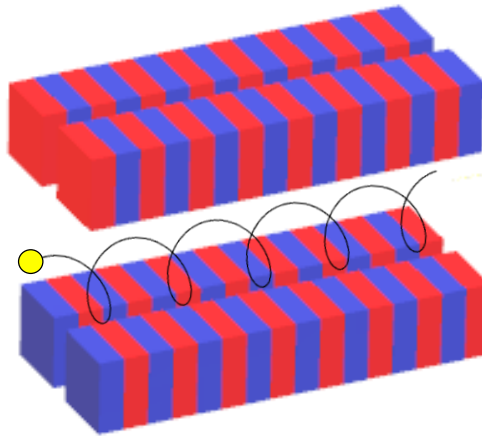
Diffraction limited
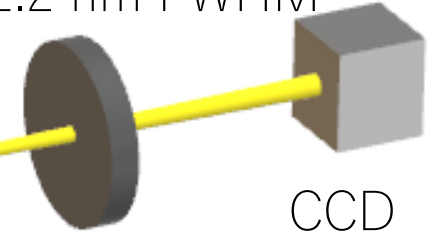Wavelength ~100 nm

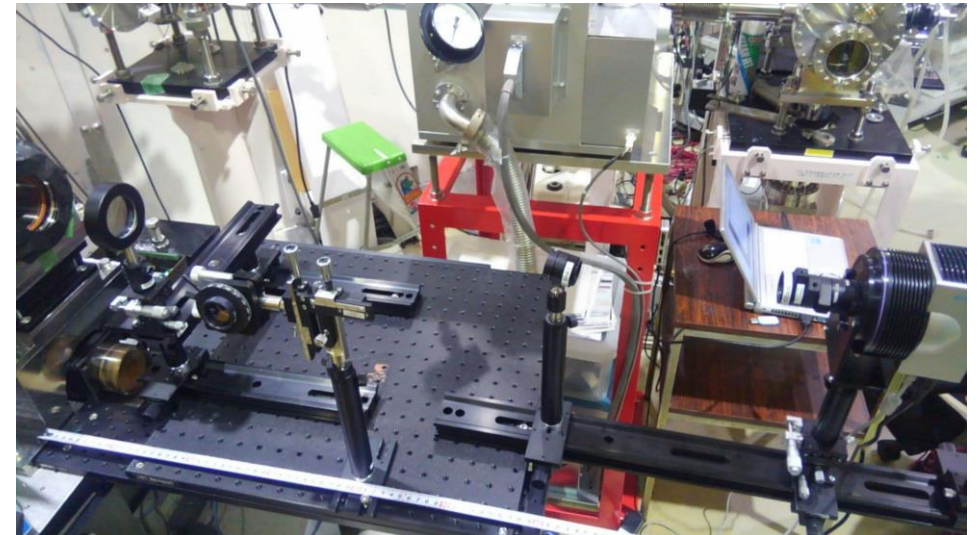# Experiment at UVSOR-III

Linear polarization
Fundamental 355 nm

Circular polarization
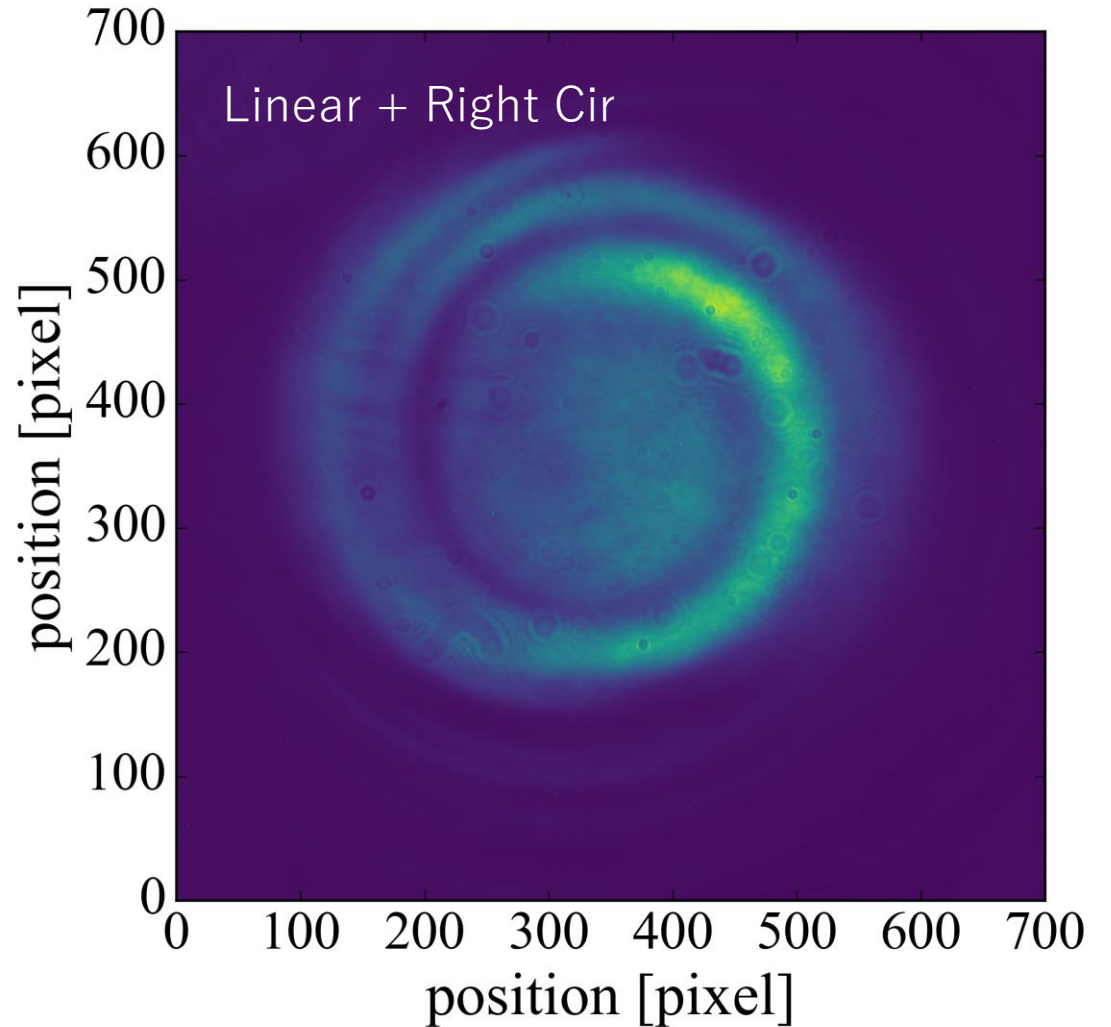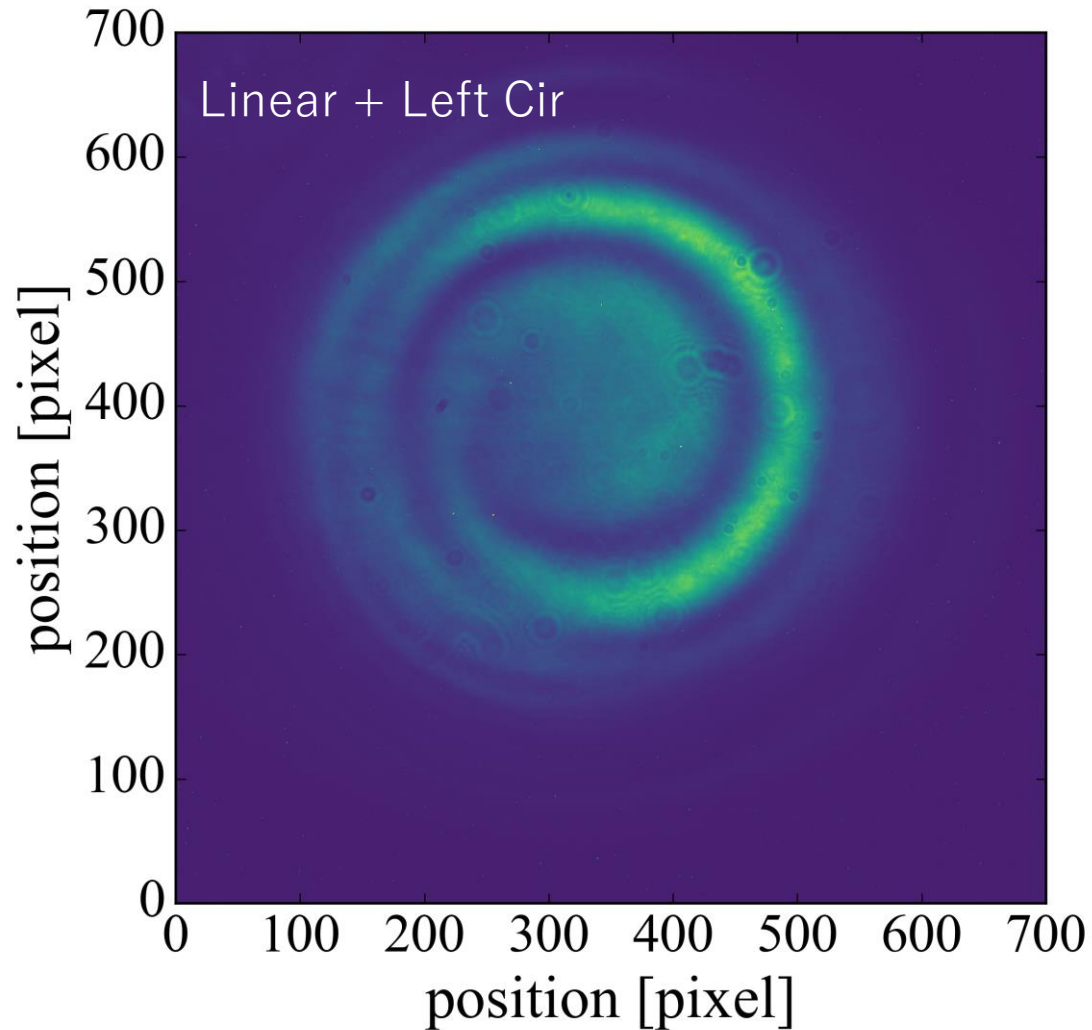Fundamental 710 nm
2nd 355 nm

Bandpass filter
355 nm ±2.2 nm FWHM

CCD
camera

Interference pattern of linear and helical

Simulation results by SRW https://github.com/ochubar/SRW
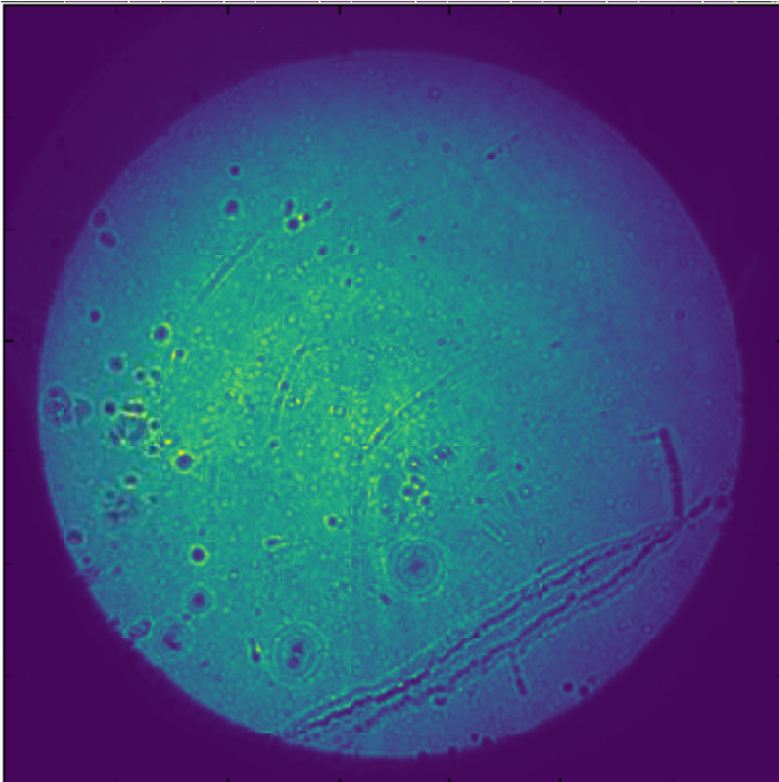
Experiment at UVSOR-III

Bandpass filter
355 nm ±2.2 nm FWHM

Phase shifter

CCD camera

Wire grid Polarizer

Left circular polarization
Fundamental 355 nm

Right Circular polarization
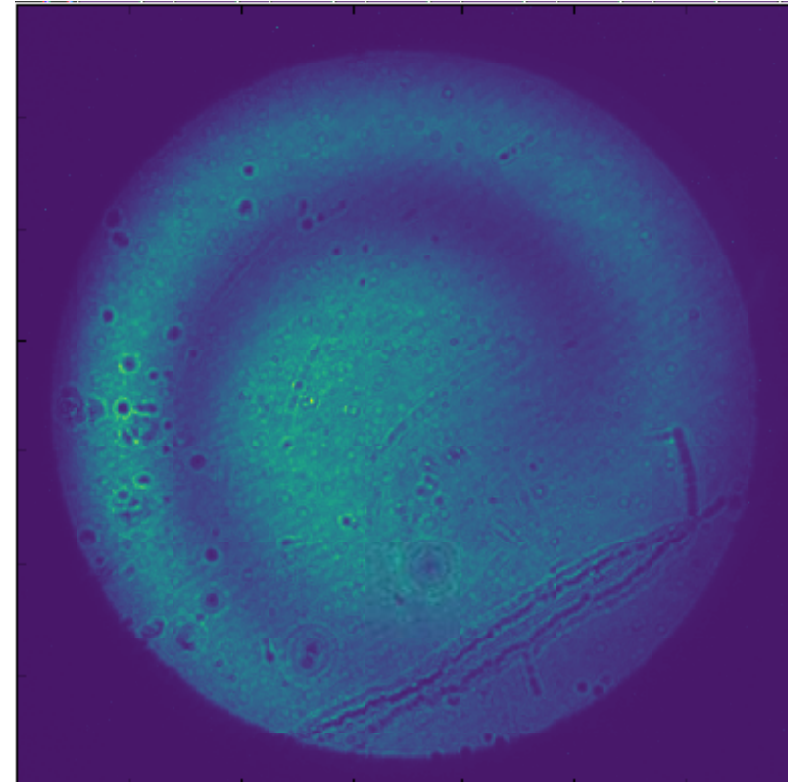Fundamental 710 nm
2nd 355 nm
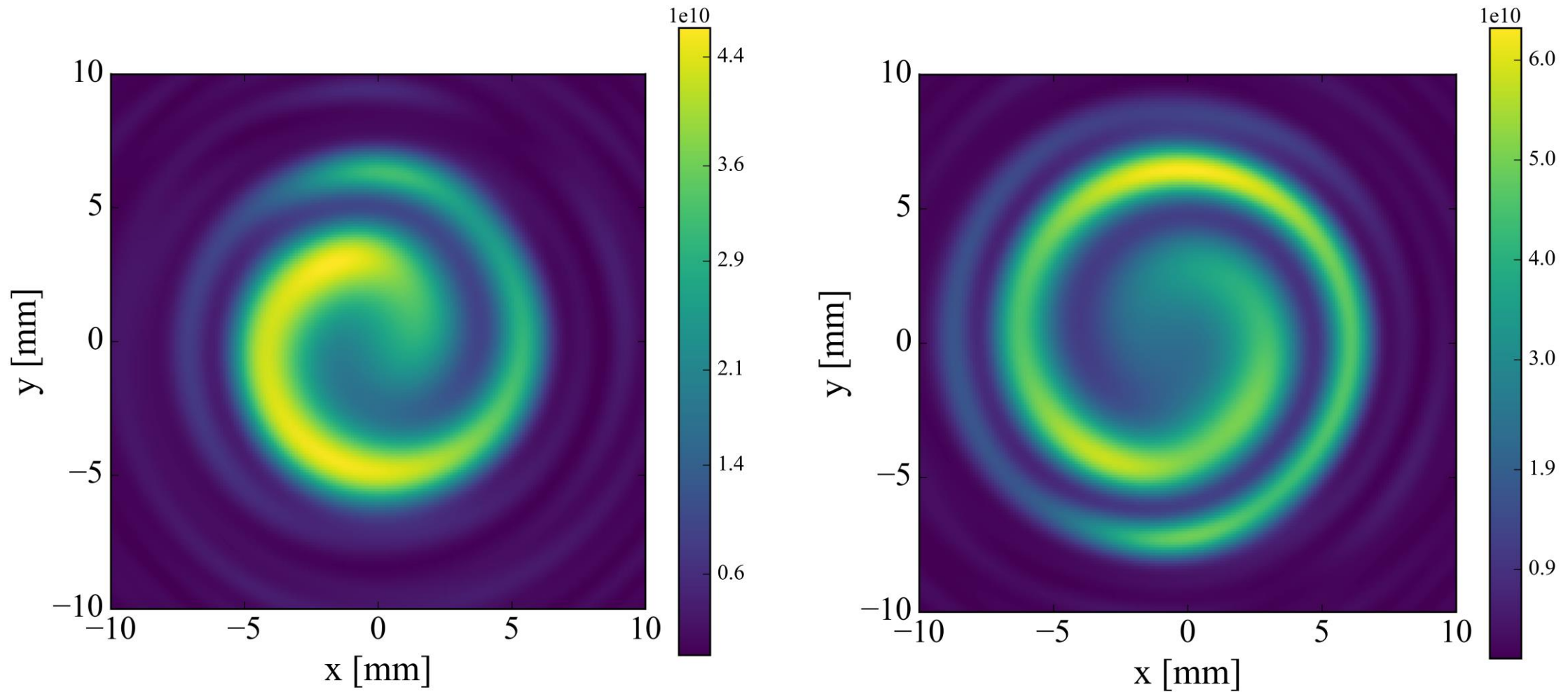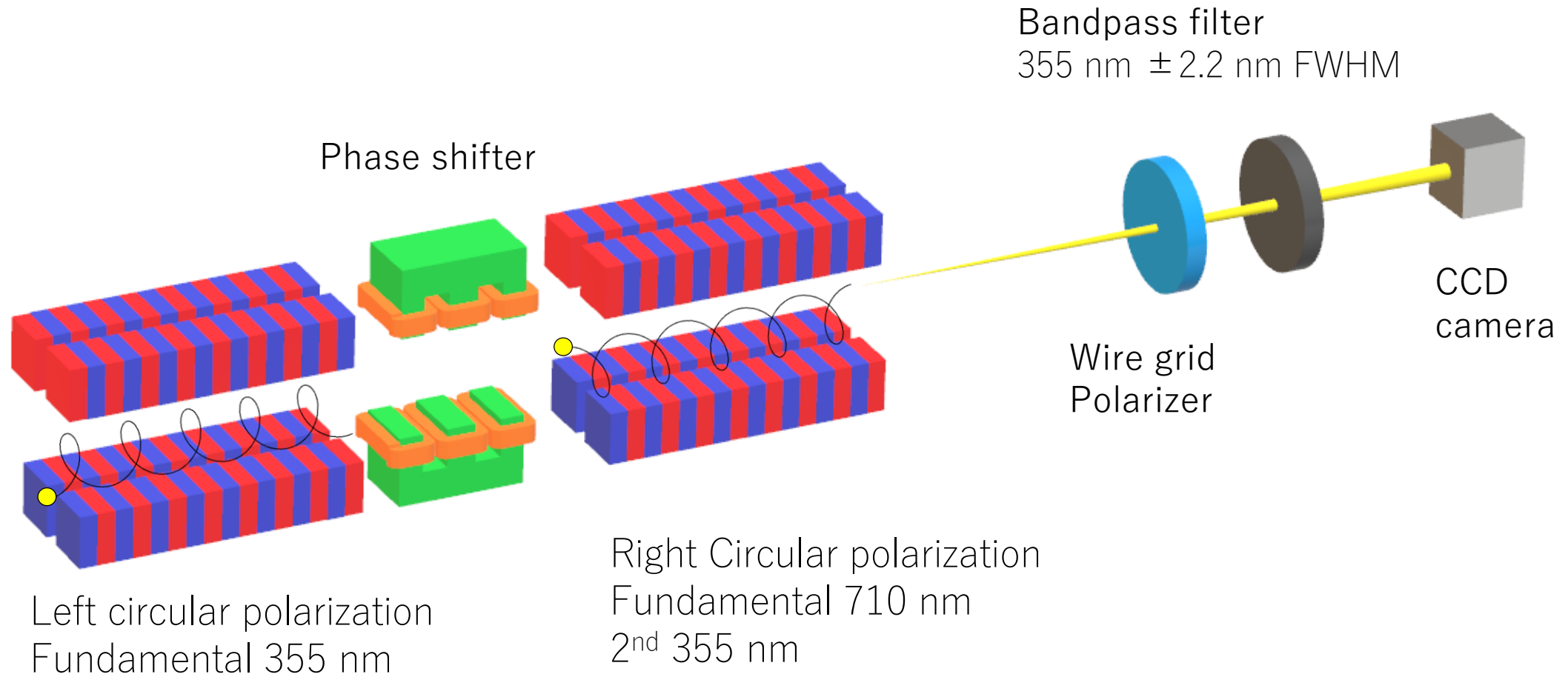
1st right circular and 2nd harmonics left circular mode
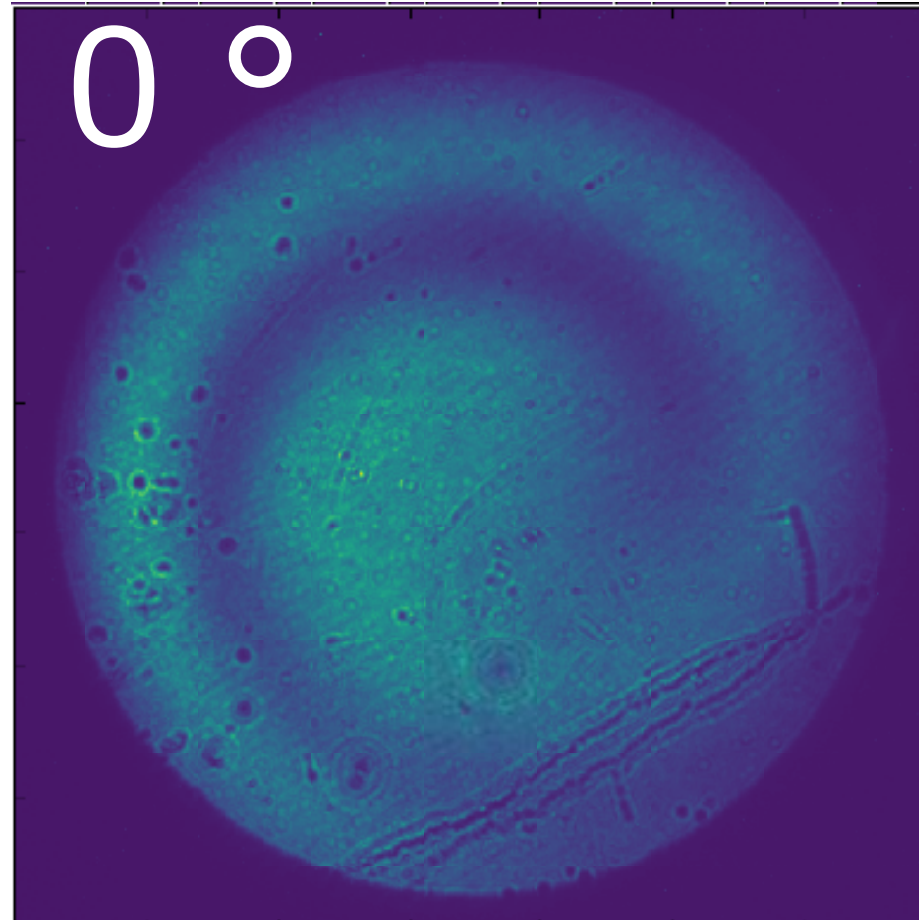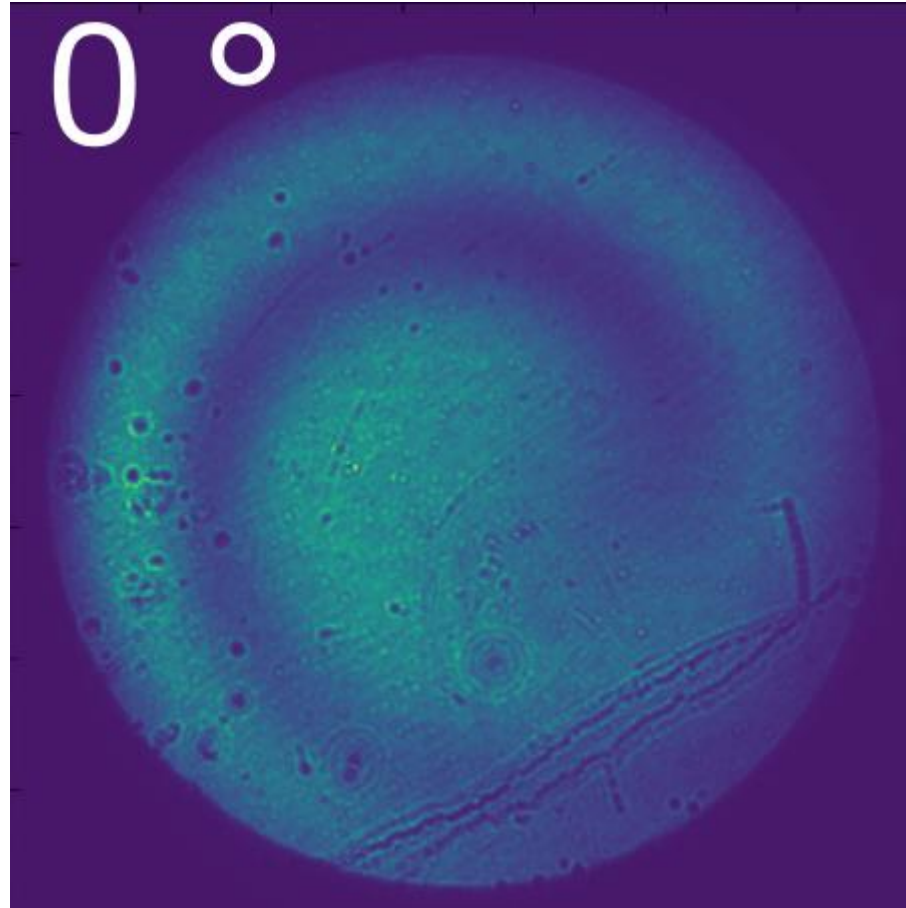
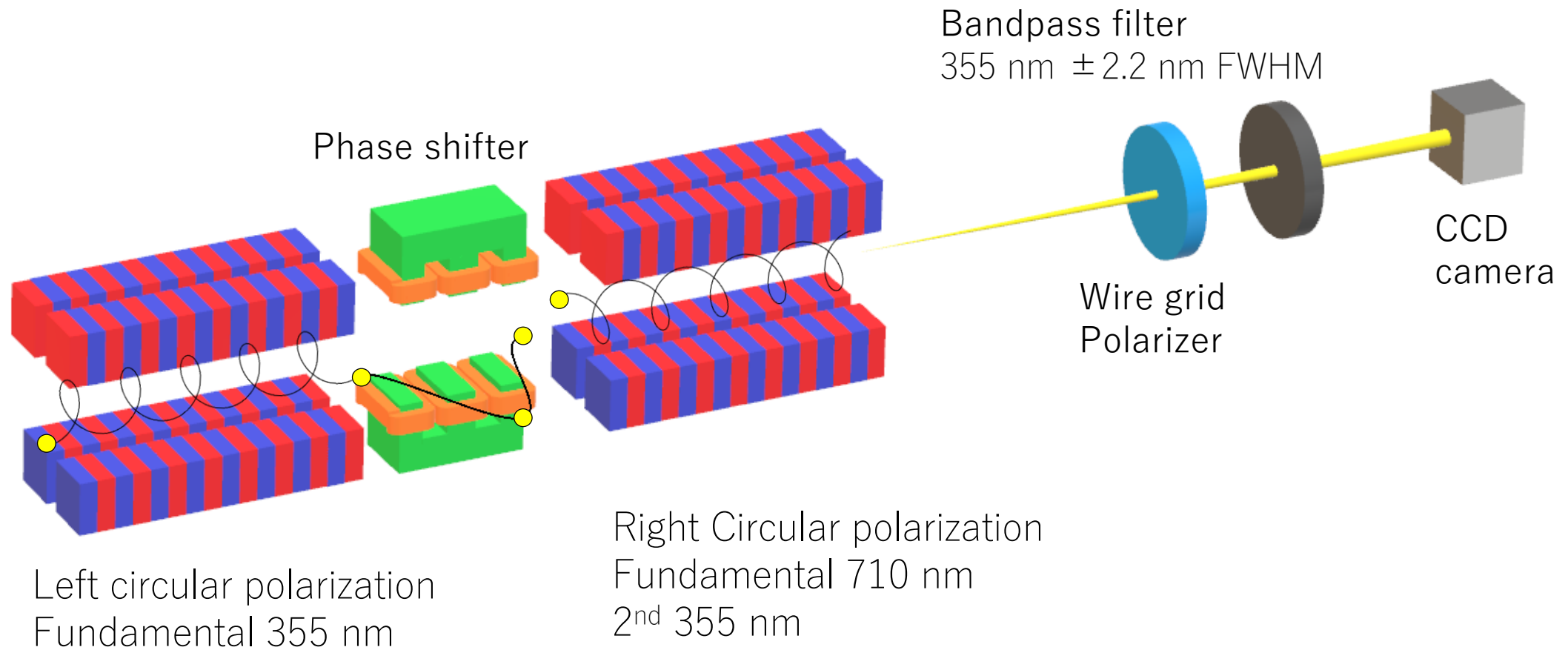### Without polarizer

With polarizer

1st right circular and 2nd harmonics left circular mode

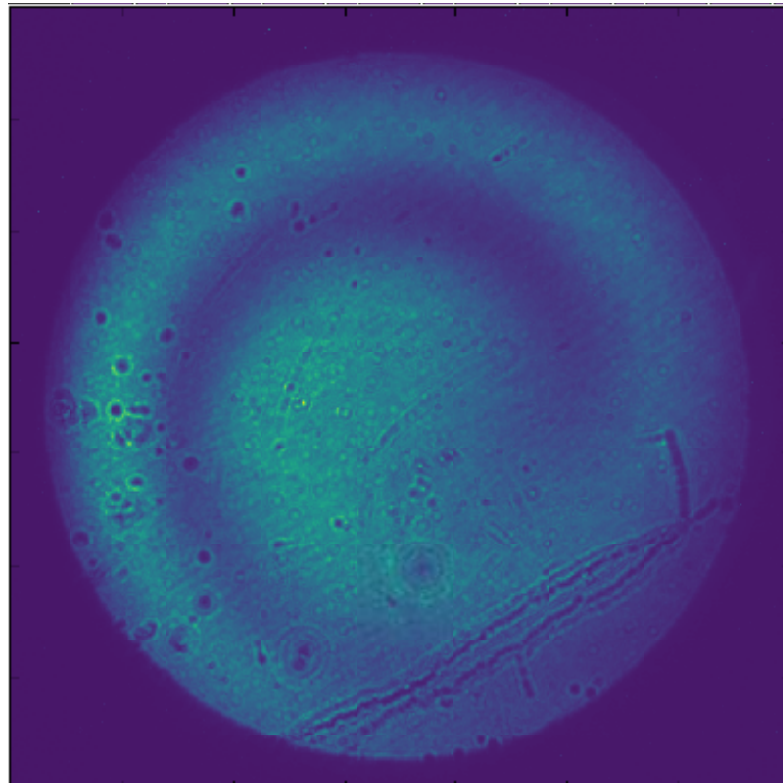# 1st right circular and 2nd harmonics left circular mode

Experiment at UVSOR-III

Phase shifter

Bandpass filter
355 nm ±2.2 nm FWHM

Wire grid
Polarizer

CCD
camera

Left circular polarization
Fundamental 355 nm

Right Circular polarization
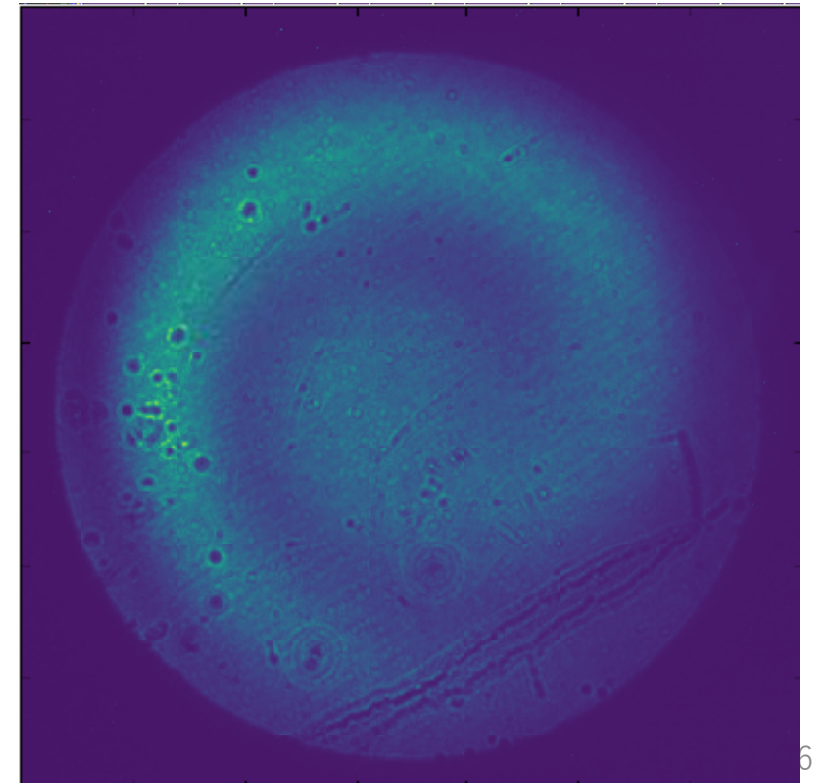Fundamental 710 nm
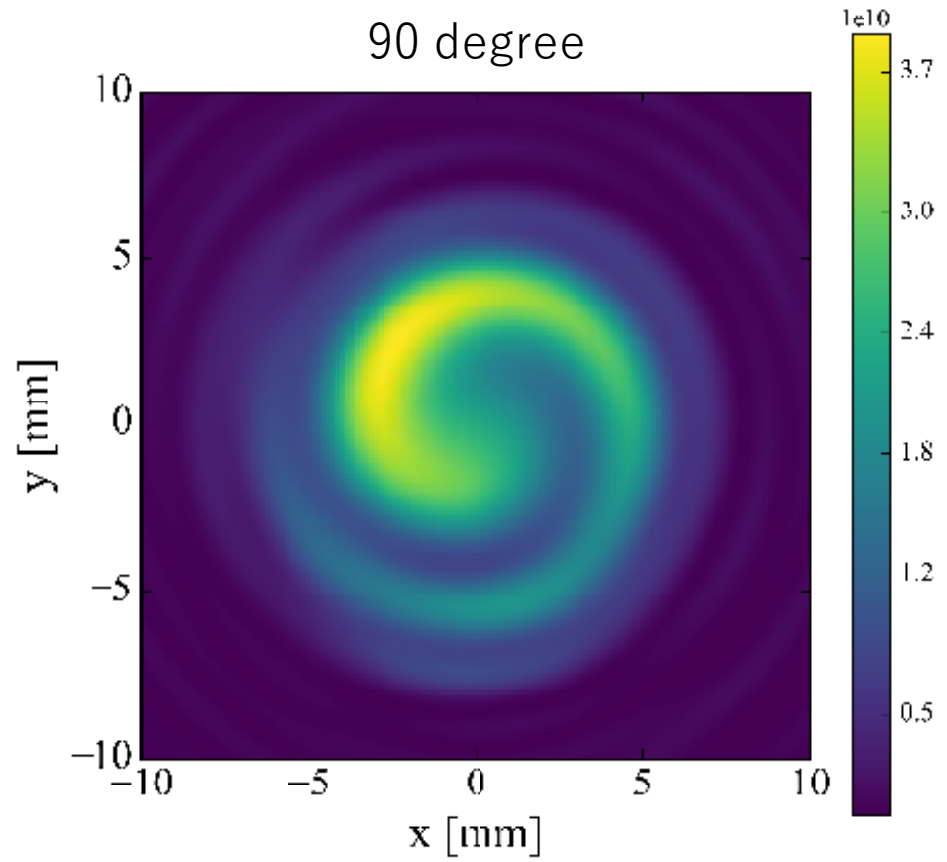2nd 355 nm

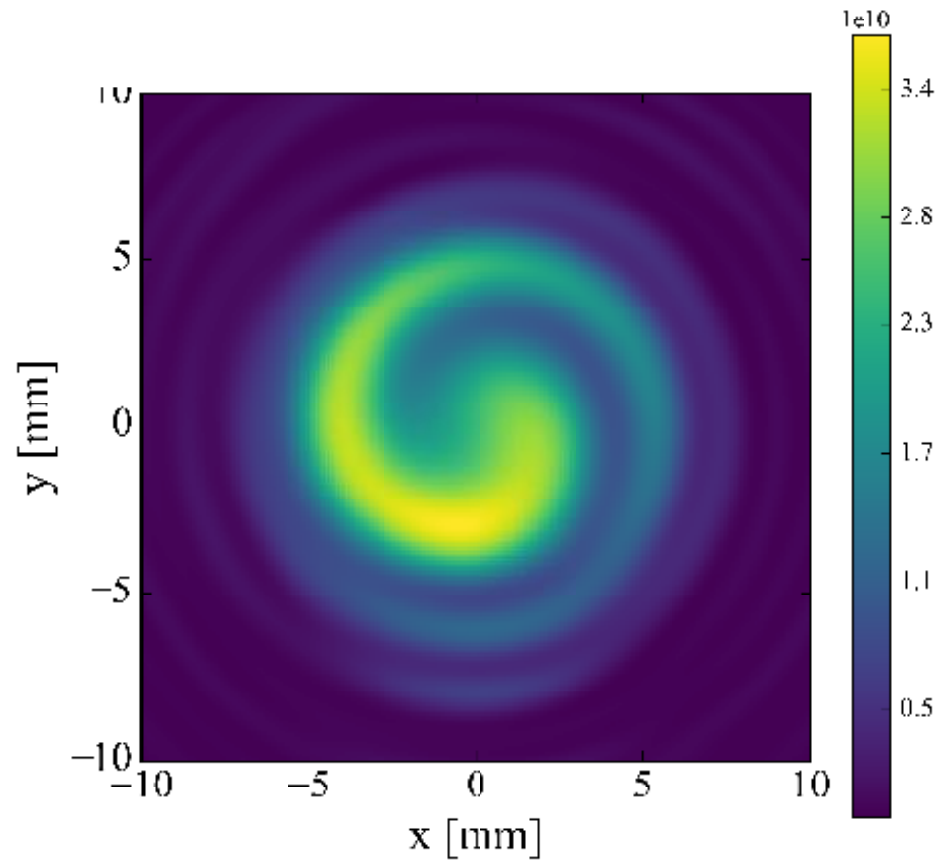# Phase shifter rotates the spiral pattern

- Bump orbit was made in between undulators by phase shifter.
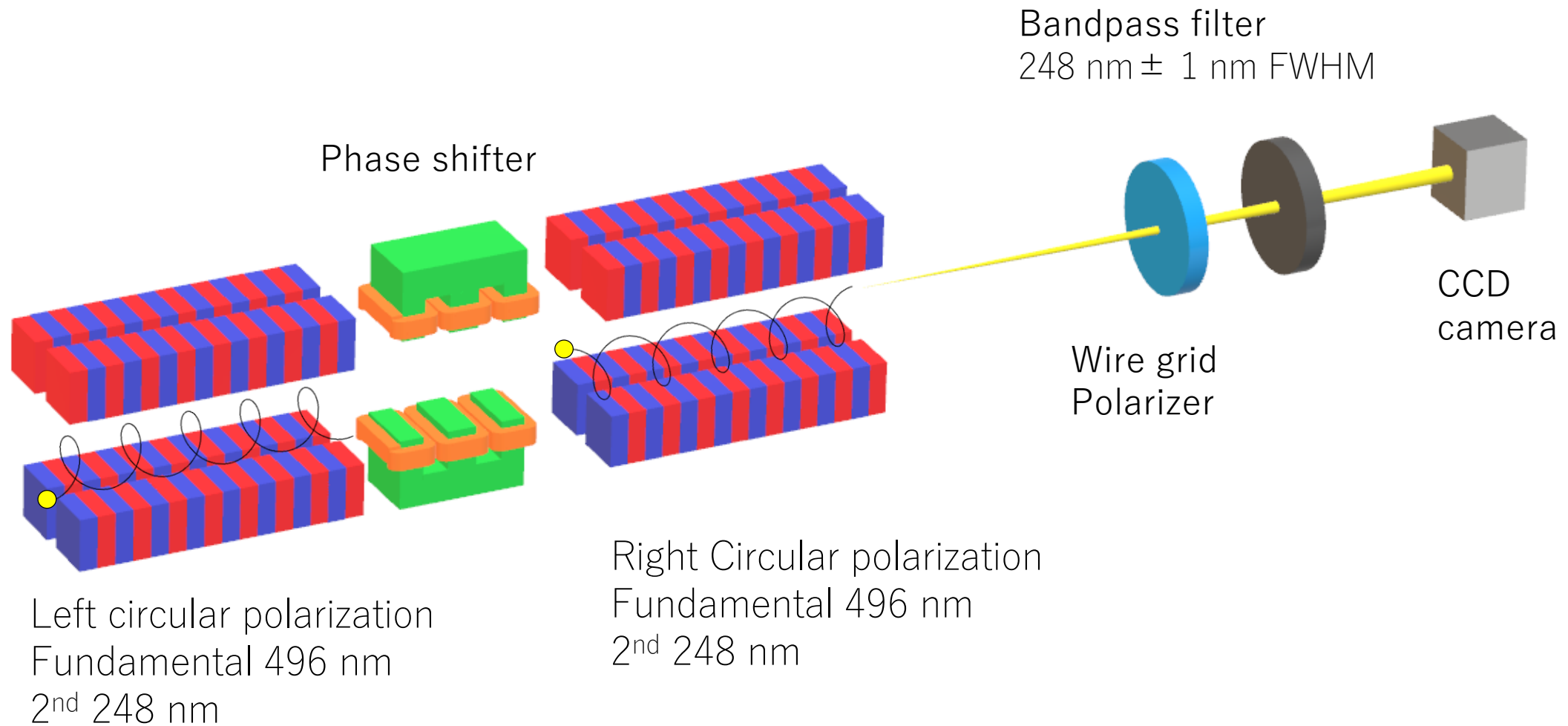 The orbit lengthening converted the relative phase retardation.

25.8° of relative phase retardation

Phase shifter simulation

90 degree

Experiment at UVSOR-III

Bandpass filter
248 nm ± 1 nm FWHM

Phase shifter

CCD camera

Wire grid Polarizer

Left circular polarization
Fundamental 496 nm
2nd 248 nm

Right Circular polarization
Fundamental 496 nm
2nd 248 nm

2ⁿᵈ harmonics right circular and 2ⁿᵈ harmonics left circular mode with polarizer
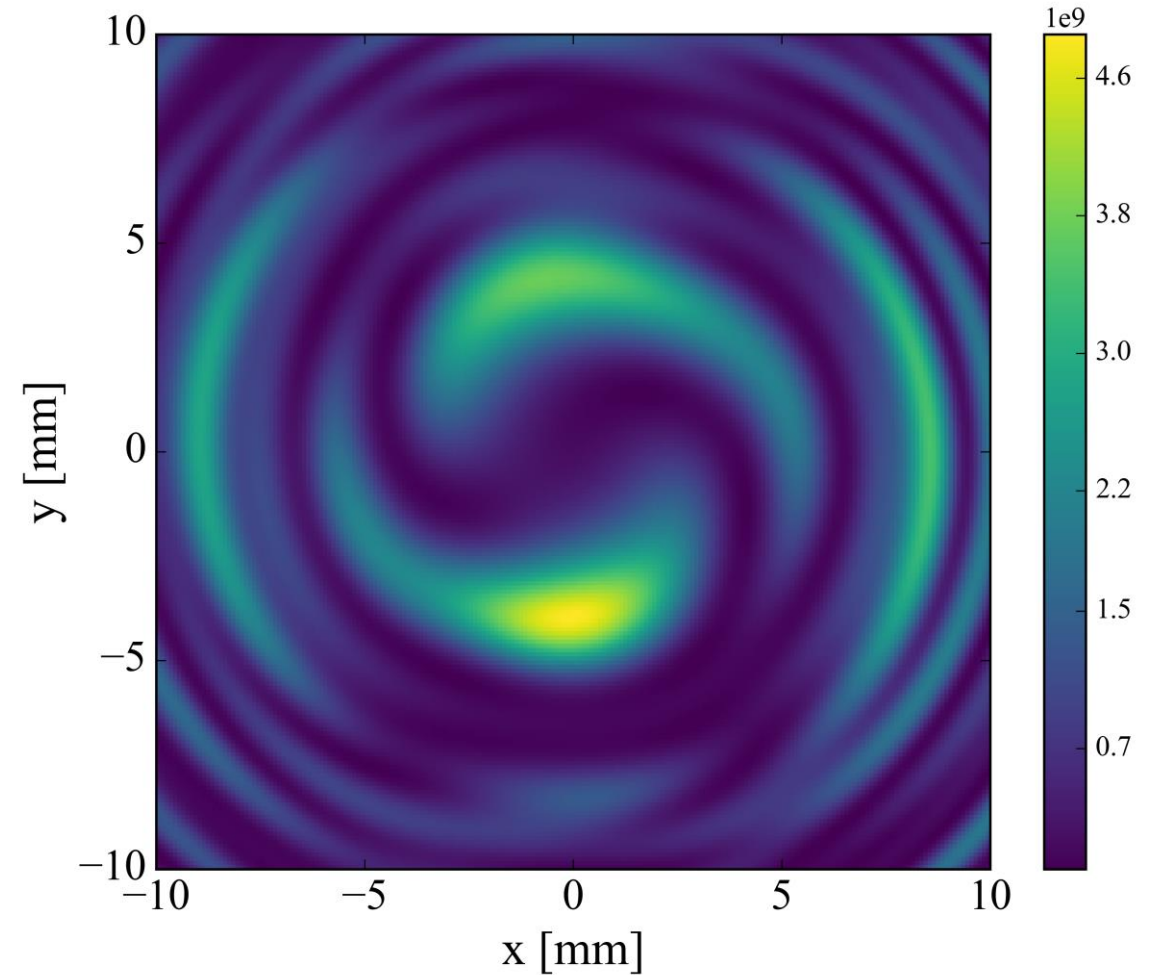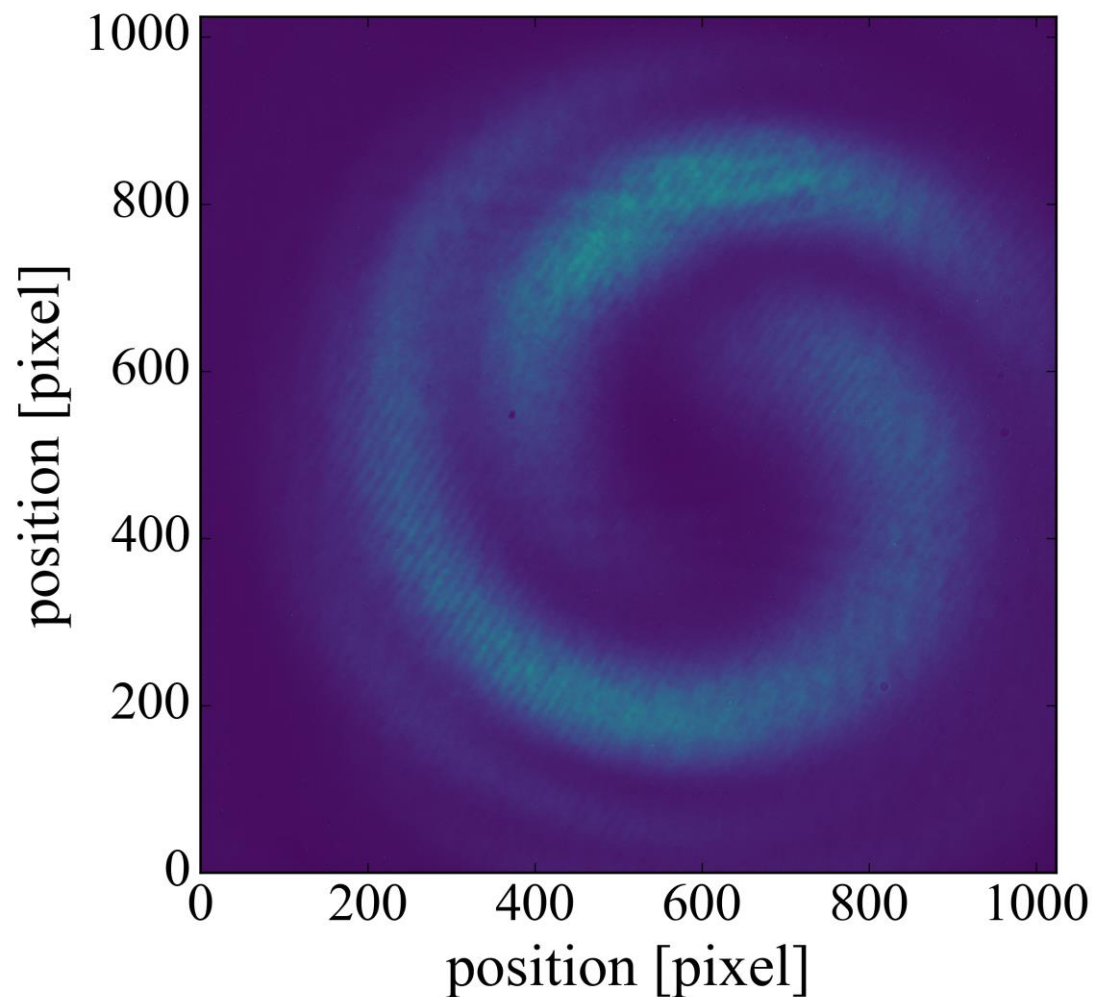
Conclusion

- Experiment on optical vortex was performed in UVSOR-III

- We measured the interference patterns of following
  - Fundamental from the linear undulator and second harmonics of right and left circularly polarized from the helical undulator.
  - Fundamental from the right circularly polarized undulator and second harmonics from the left circularly polarized helical undulator.
  - Second harmonics from the left circularly polarized and right circularly polarized helical undulators.