



High energy X-ray vortex generation using inverse Compton scattering

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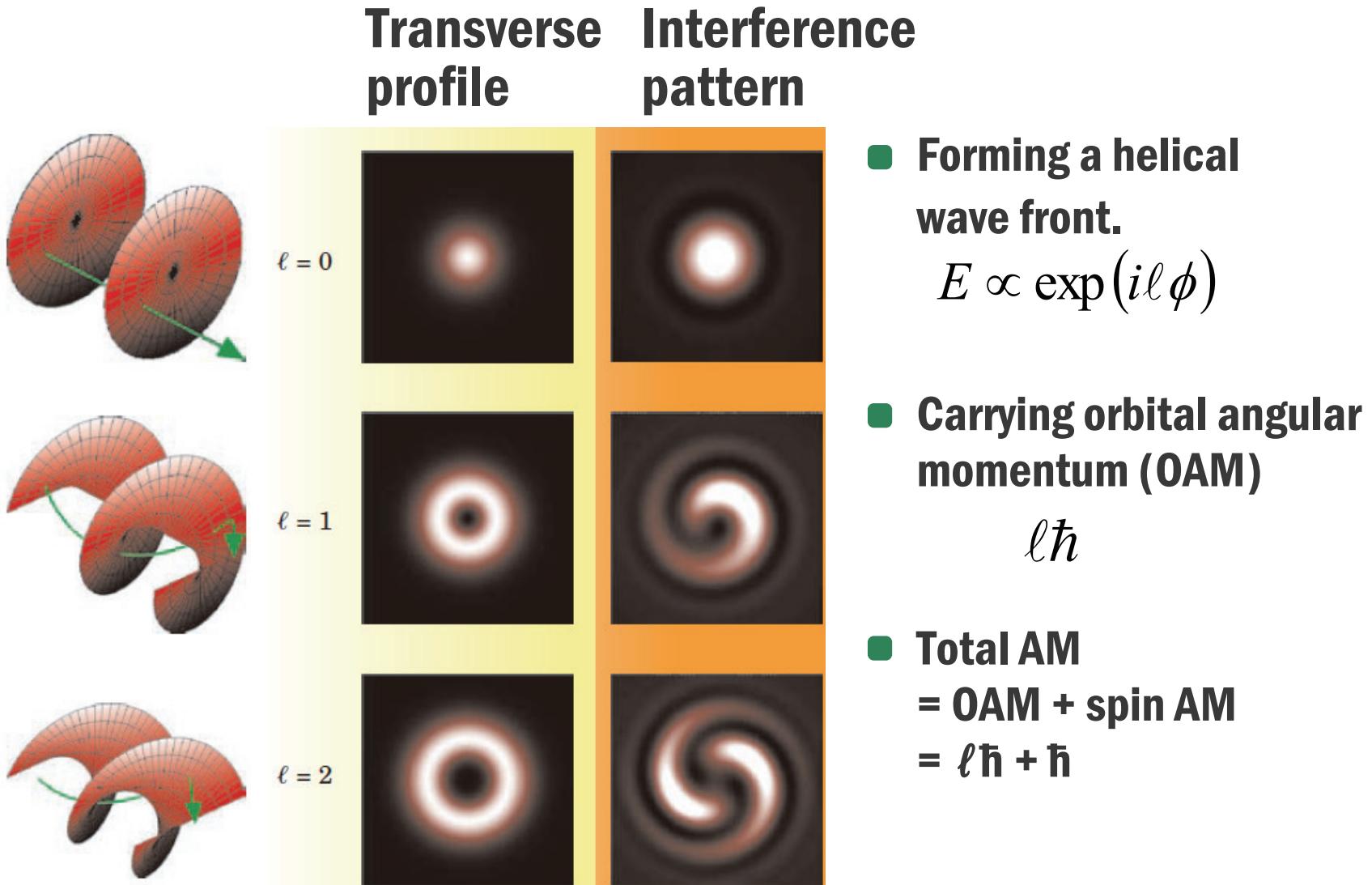
Daniel Seipt (Helmholtz Institut Jena).

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Outline

- Vortex beams carrying orbital angular momentum
- High energy X-ray (gamma-ray) vortex generation
- Summary

Optical vortex

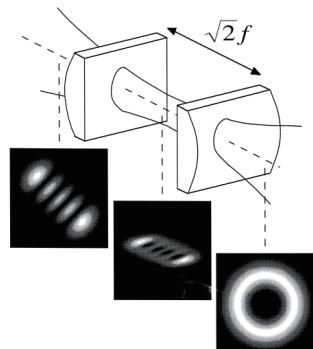


M. Padgett et al., Phys. Today 57 (2004) 35.

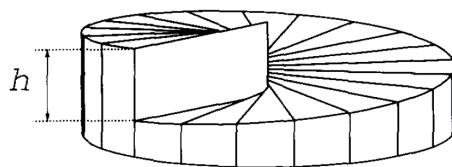
Generation

Special filters

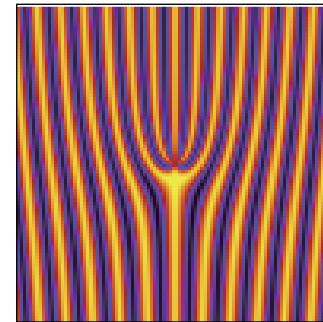
Cylindrical lens



Spiral phase plate



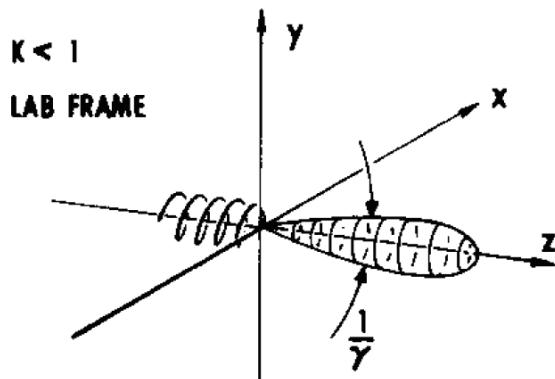
Hologram



J. Courtial et al., Opt. Comm. 159 (1999) 13.

M. W. Beijersbergen et al., Opt. Comm. 112 (1994) 321.

Without filters

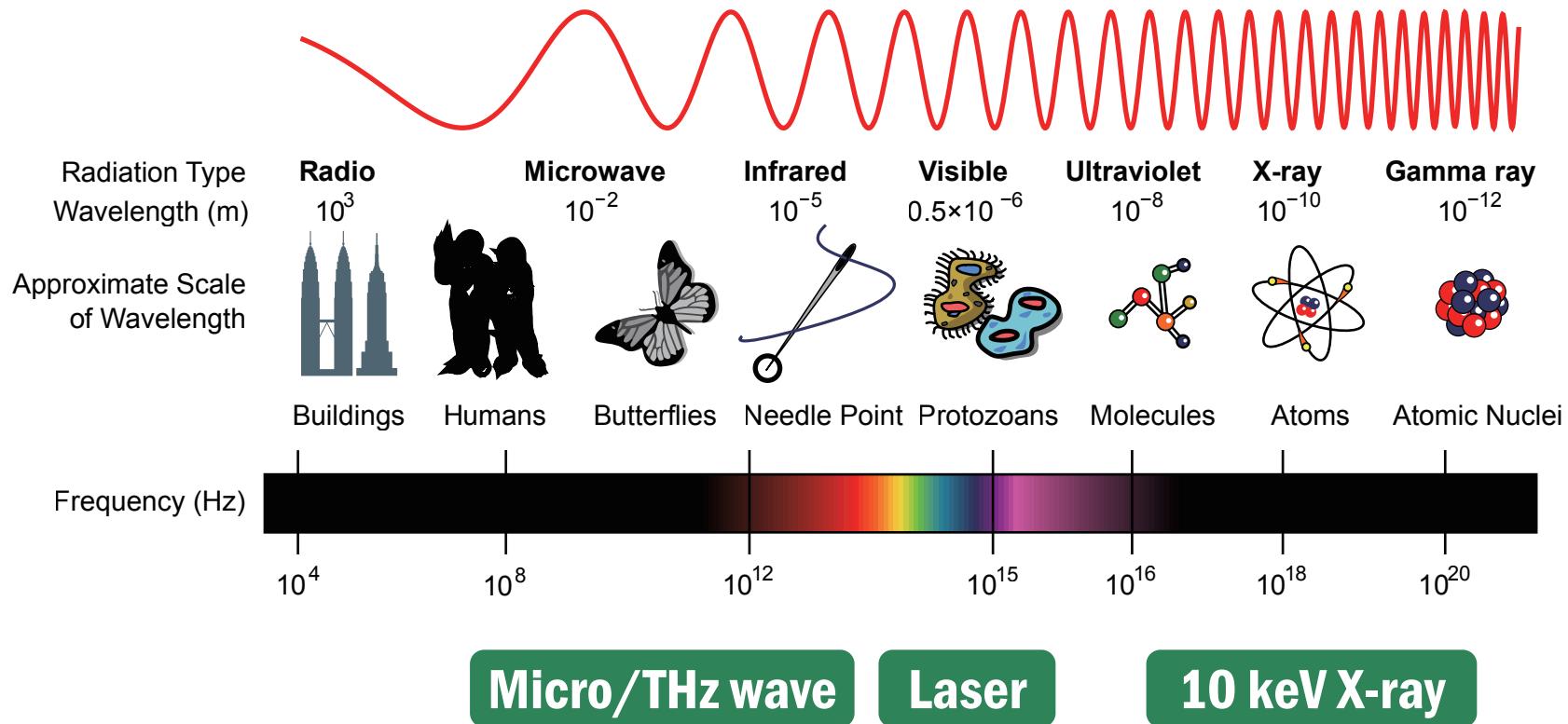


**Electromagnetic radiation
from an electron**

Main topic of this talk

B. M. Kincaid et al., J Appl Phys 48 (1977) 2684.

Vortex beams



Wikipedia.

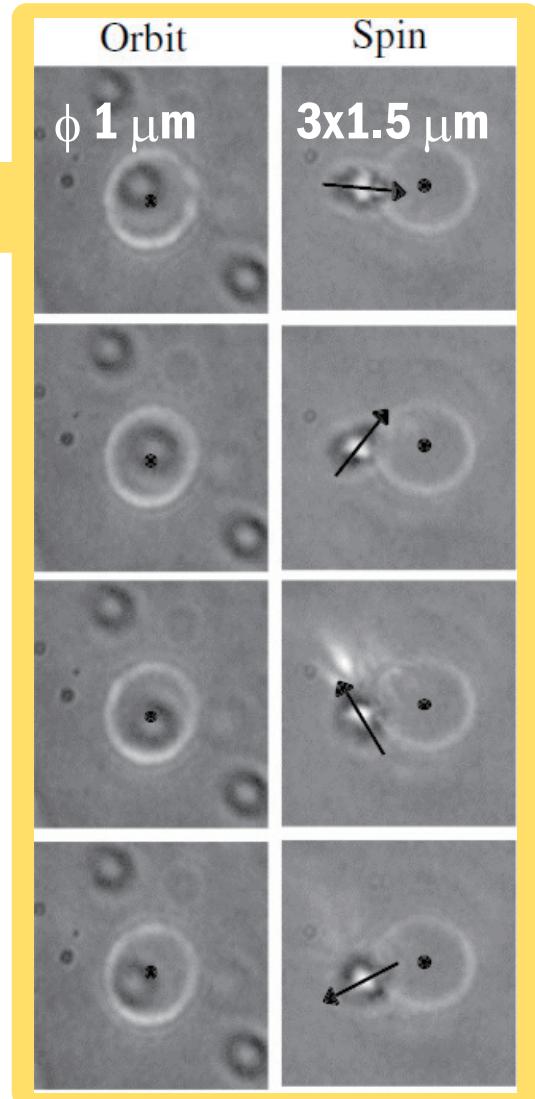
Application of vortex beams

Experimental demonstration

- OAM transfer to micro particle
- Quantum entanglement
- Creation of metal nano needle
- Terabit data transmission

Theoretical proposal

- X-ray dichroism
- Magnetic mapping using electron vortex
- Direct observation of rotating black hole



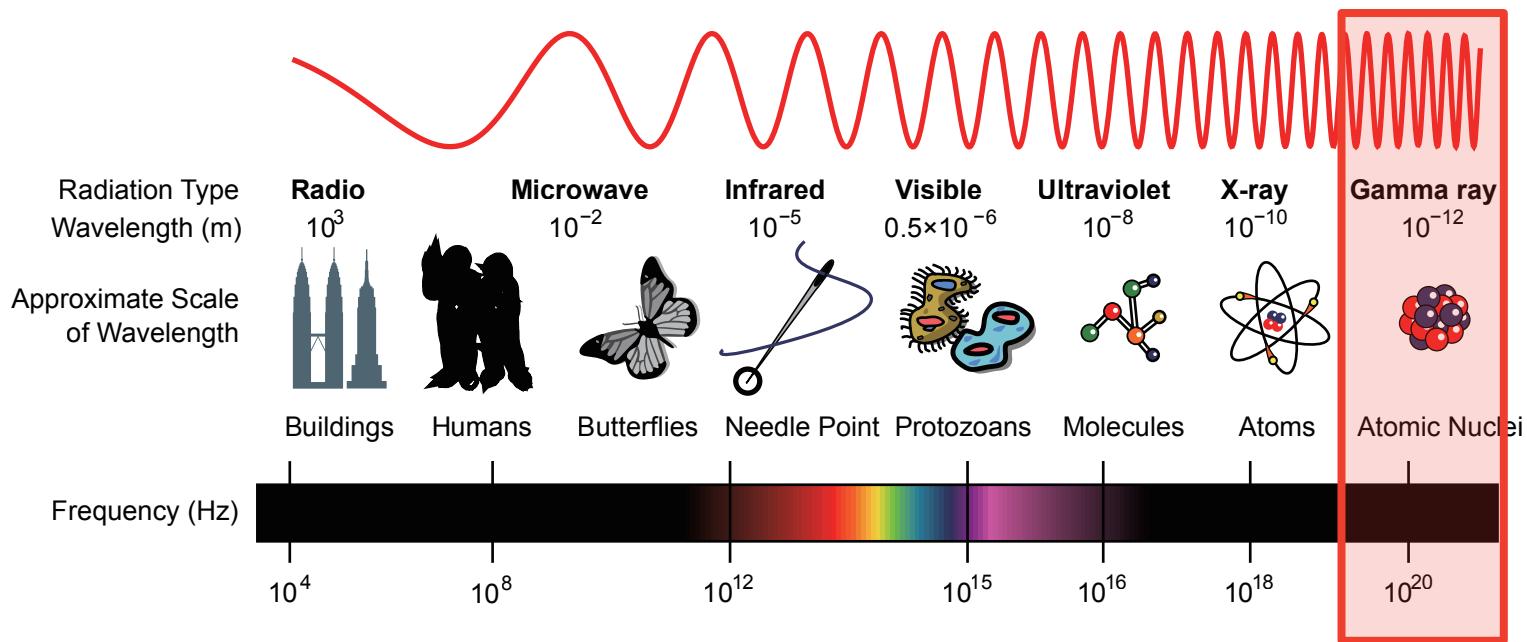
A. T. O'Neil et al., Phys. Rev. Lett. 88 (2002) 053601.

Outline

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Purpose

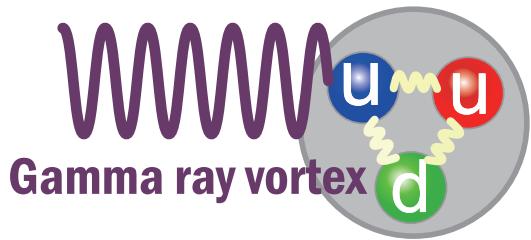
**Generation of gamma ray vortex (> MeV)
and development its application.**



Application possibility

Insight into the proton structure

I. P. Ivanov, Phys. Rev. D 83 (2011) 093001.



If the OAM of gamma ray is transferred to the quark/gluon, it becomes novel probe of the proton spin.

Nuclear physics

Y. Taira et al., arXiv 1608 (2016) 04894.

Excited states can be populated by high order transition.
Photon-induced reaction cross section will be changed.

Generation of positron vortex via pair production

As a new particle source for high energy physics.

How to generate gamma ray vortex ?

- 1 Frequency upconversion of an optical vortex laser by inverse Compton scattering (ICS)

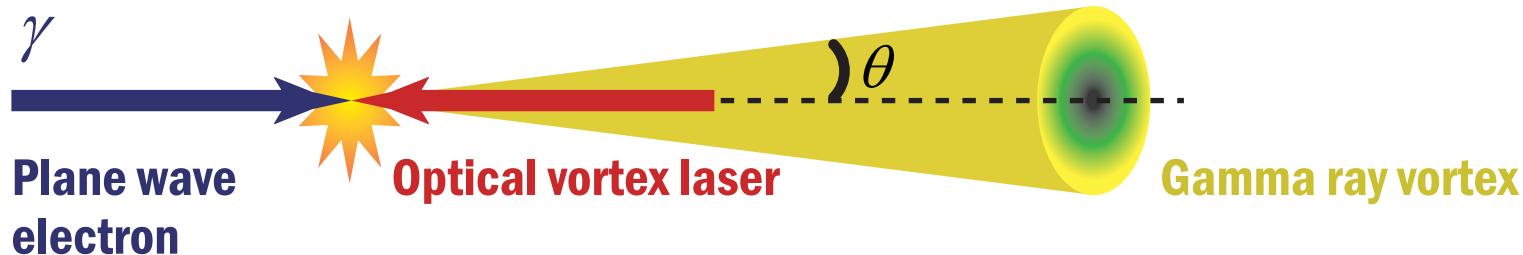
U. D. Jentchura et al., PRL 106 (2011) 013001.

- 2 Nonlinear inverse Compton scattering of intense circularly polarized laser (not vortex laser)

Y. Taira et al., arXiv 1608 (2016) 04894.

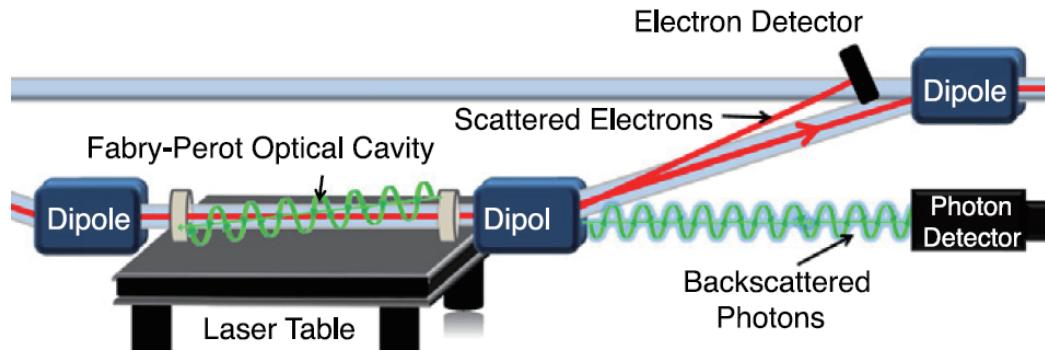
Compton backward scattering of circularly polarized gamma ray

ICS of optical vortex laser



It was predicted that OAM of the laser is preserved at the very small angle $\theta < 1/\gamma^2$.

JLab Compton polarimeter



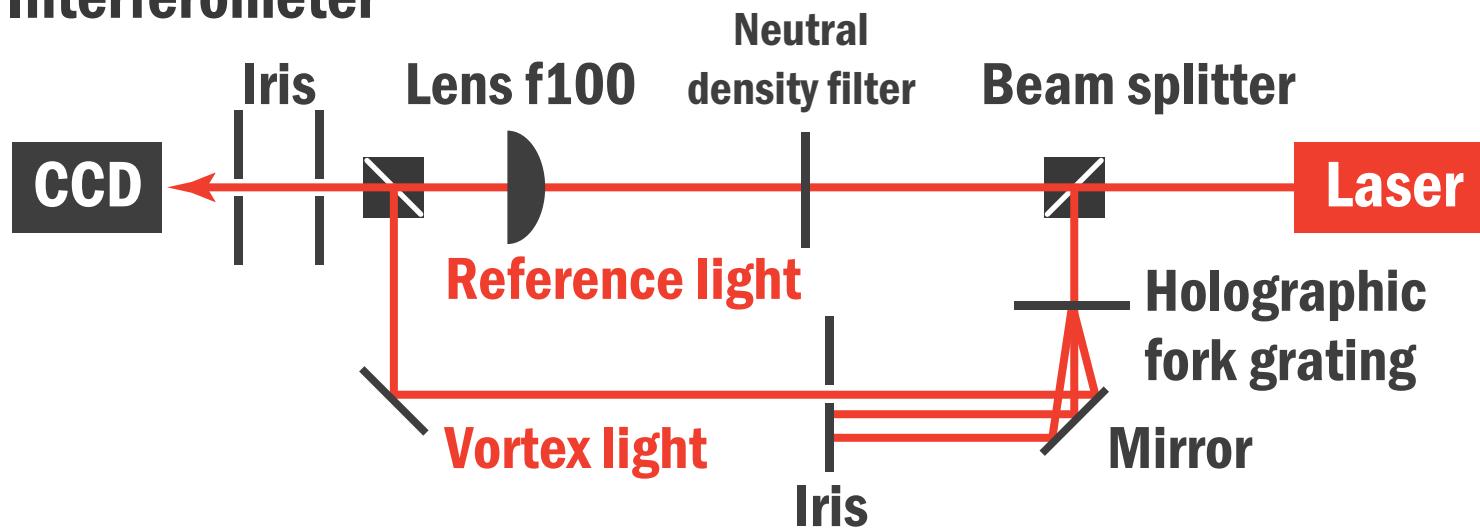
Fabry-Perot cavity
Stored power: 1000 W

To exceed background, more than 100 W vortex laser is required.

T. Allison et al., NIMA 781 (2015) 105.

Measurement technique of vortex laser

Interferometer

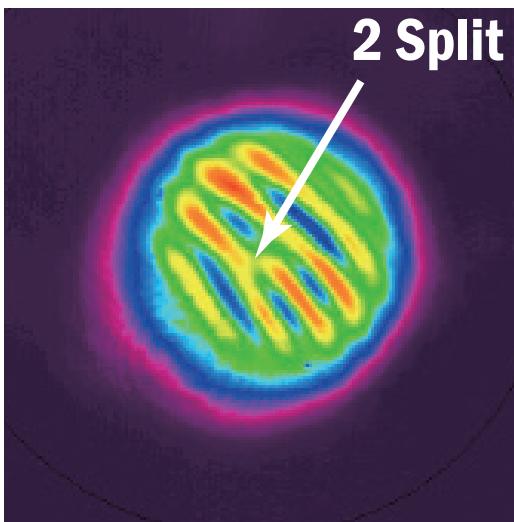


Interference pattern

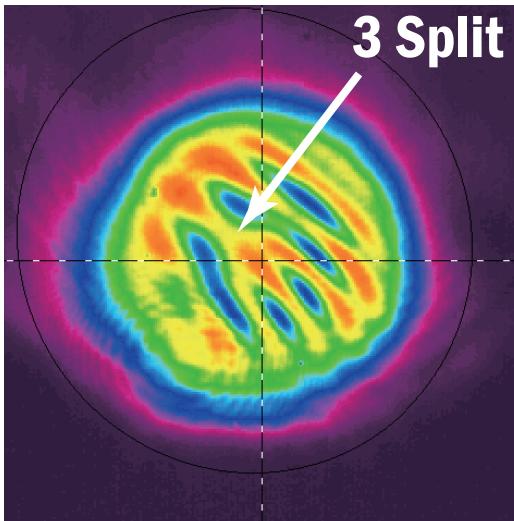
OAM value

Plane wave + vortex

1

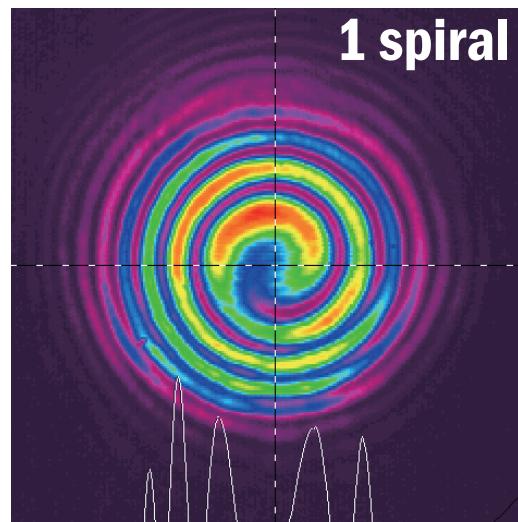


2

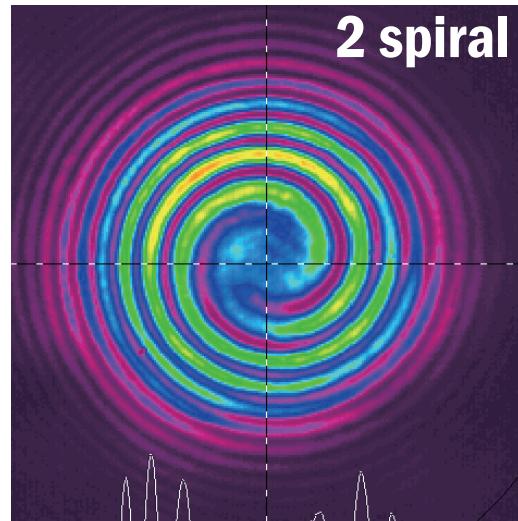


Spherical wave + vortex

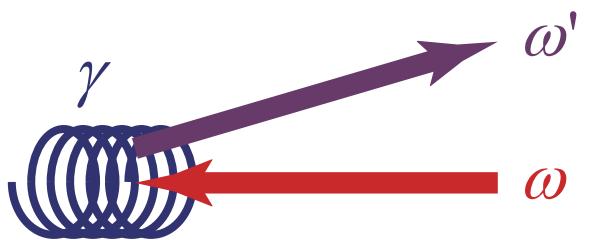
1 spiral



2 spiral



Nonlinear ICS of circularly polarized laser

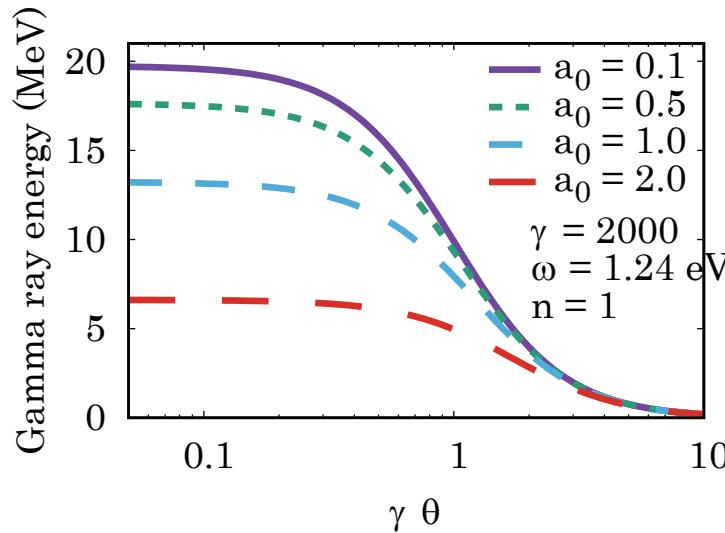


Intense laser with a laser strength parameter, a_0

Helical motion is induced by the circularly polarized laser ($a_0 \approx 1$) and this motion emits n-th higher harmonic and vortex radiation.

Energy

$$\omega' = \frac{8n\gamma^2\omega}{2\gamma^2\theta^2 + 2 + a_0^2}$$



Electric field and Stokes parameter

Electric field in the x-y plane

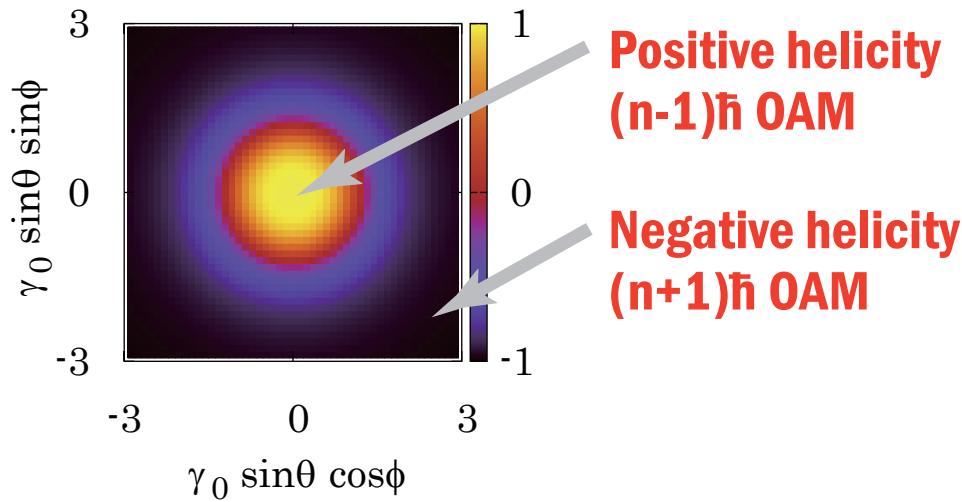
$$E = \frac{i}{\sqrt{2}} (C_\theta \cos \theta + C_\phi) \exp \{i\psi_0 + ikR + i(n-1)\phi\} e_+$$
$$+ \frac{i}{\sqrt{2}} (C_\theta \cos \theta - C_\phi) \exp \{i\psi_0 + ikR + i(n+1)\phi\} e_-$$

$$e_\pm = \frac{e_x \pm ie_y}{\sqrt{2}}$$

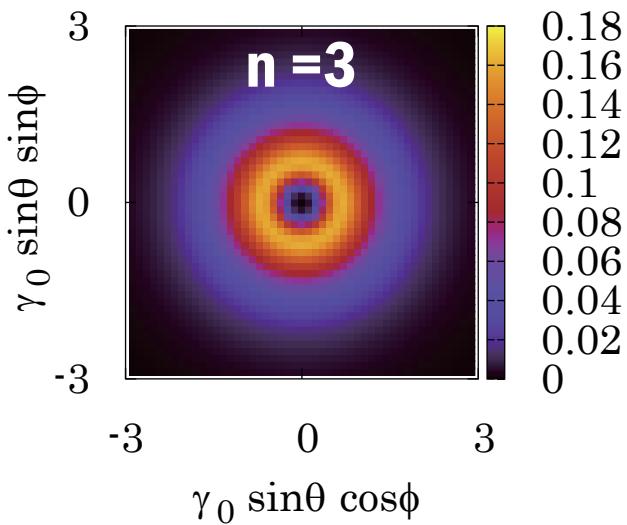
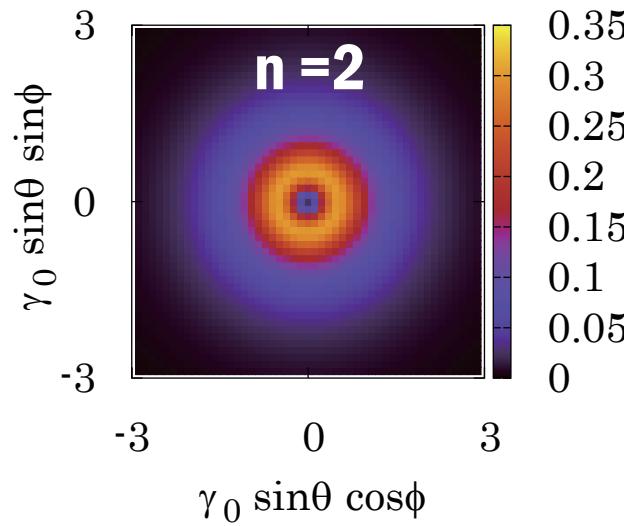
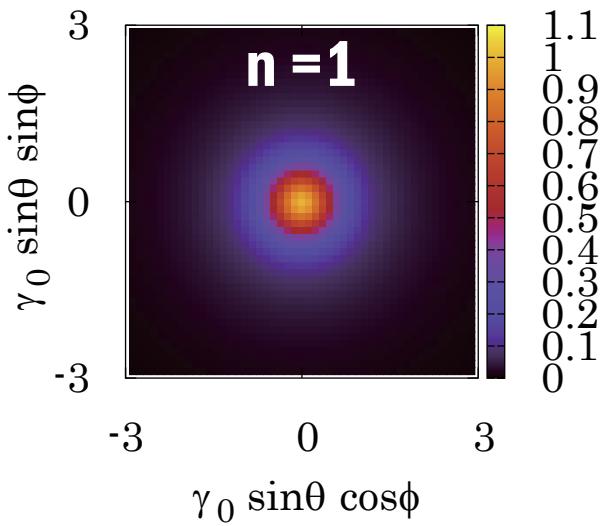
Positive helicity carry $(n-1)\hbar$ OAM

Negative helicity carry $(n+1)\hbar$ OAM.

Degree of circular polarization



Spatial distribution



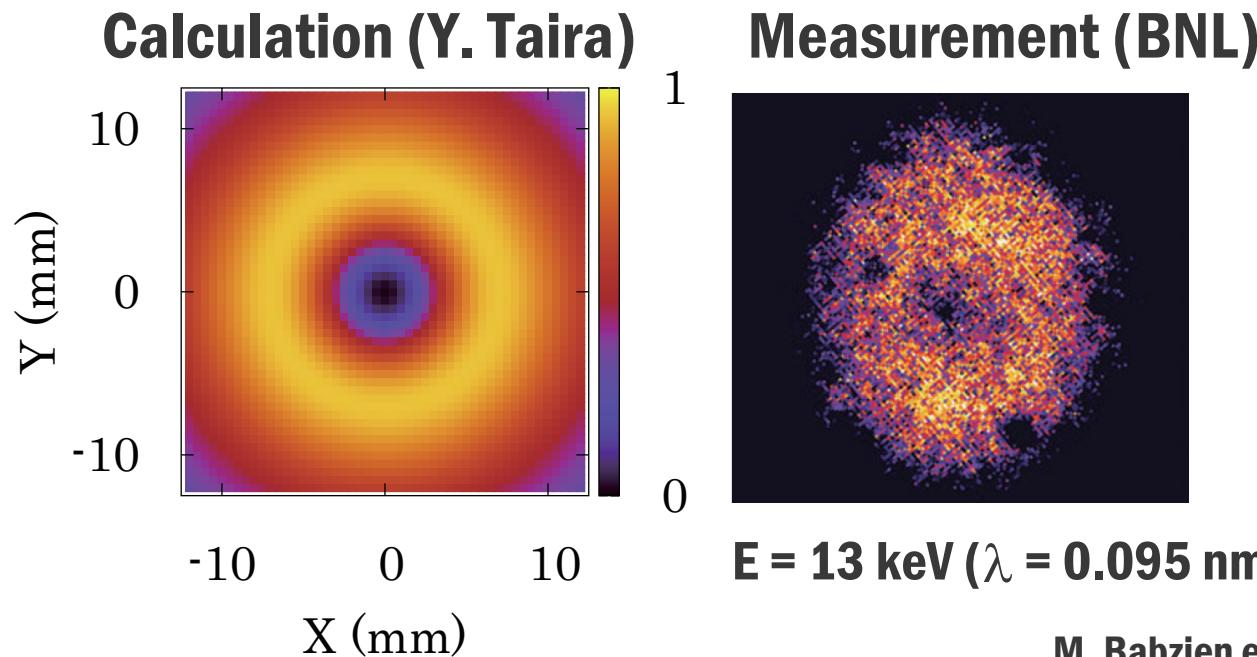
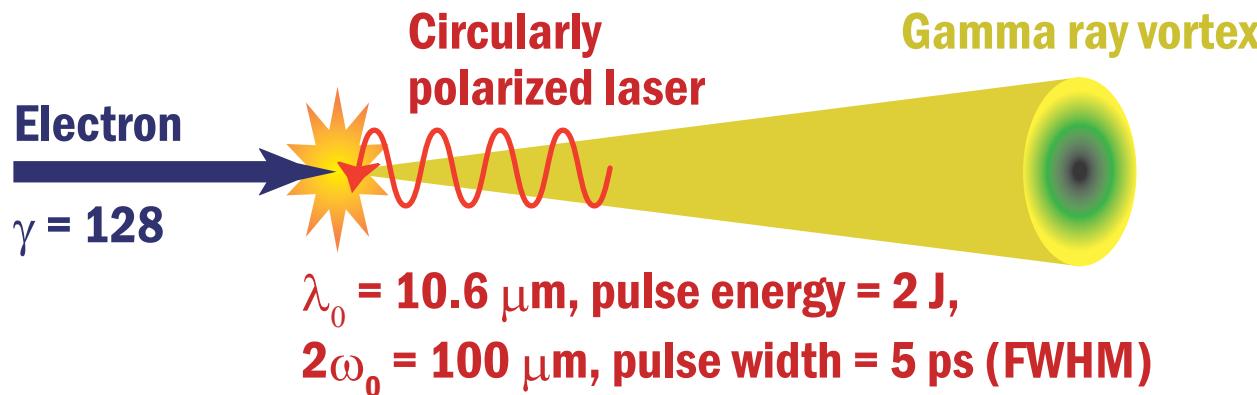
**Annular shape of higher harmonic
is due to the helical wavefront.**

Characteristics of nonlinear ICS gamma-ray

Helicity	Positive	Negative
Fundamental ($n = 1$)		
N	60×10^{10} photons/sec	2×10^{10} photons/sec
E	11-13 MeV	2.6-2.7 MeV
OAM	0	$2\hbar$
2nd harmonics		
N	20×10^{10} photons/sec	2×10^{10} photons/sec
E	21-26 MeV	5.2-5.5 MeV
OAM	\hbar	$3\hbar$

$$a_0 = 1.0, \lambda_0 = 1.0 \text{ } \mu\text{m}, \gamma_0 = 2000, N_e = 10^9 \text{ electrons/sec}$$

Second harmonic X-rays at BNL ($a_0=0.6$)



M. Babzien et al., PRL. 96 054802 (2006).
Y. Sakai et al., PRSTAB 18 060702 (2015).

Conclusion

- **Gamma ray vortex providing an additional degree of freedom will open new research opportunities!**
- **Gamma-ray vortex can be generated by several methods using the Compton scattering.**
- **Measurement of gamma ray vortex is a big issue.**
Interferometry, Dichroism, and Pair production are candidates.

Thank you for your attention!