National Institute of Advanced Industrial Science and Technology
AIST

Meeting at JLab, 4/21/2016

Vortex gamma ray generation

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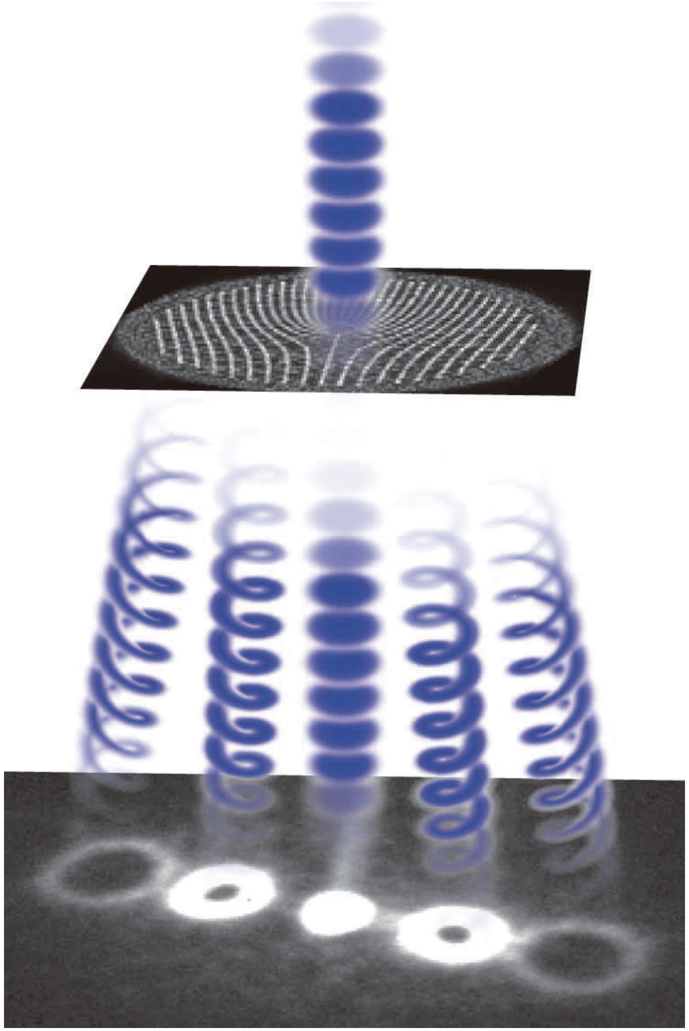
Twisted (Vortex) beam



B. J. McMorran et al., Science 331 (2011) 192.

Characteristics

- Forming herical wavefronts carrying an orbital angular momentum (OAM).
- Possessing a phase singularity at the center of helical wavefronts.
- Total angular momentum, J = S + L
  S: spin angular momentum
  L: orbital angular momentum

Generation

- Cylidrical lens
- Spiral phase plate
- Fork grating

Twisted (Vortex) beam

Already generated

Laser

L. Allen et al., Phys. Rev. A 45 (1992) 8185.

Low energy electrons (< 1 MeV)

M. Uchida et al., Nature 464 (2010) 737. J. Verbeeck et al., Nature 467 (2010) 301.
B. J. McMorran et al., Science 331 (2011) 192.

X-rays (< 10 keV)

A. G. Peele et al., Opt. Lett. 27 (2002) 1752. J. Bahrdt et al., Phys. Rev. Lett. 111 (2013) 034801.

Terahertz radiation

G. A. Turnbull et al., Opt. Comm. 15 (1996) 183. R. Imai et al., Opt. Lett. 39 (2014) 3714.

Thermal neutrons

C. W. Clark et al., Nature 525 (2015) 504.

Not developed yet

High energy electrons (> 1 MeV)

High energy X-rays (> 10 keV)

Muon, Proton, Neutrino....

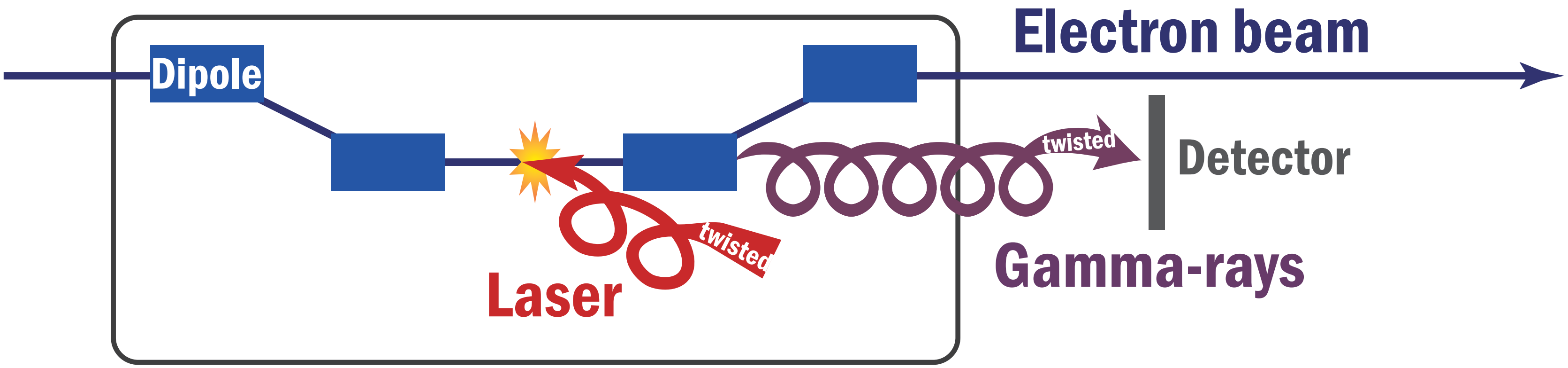
Purpose

Make clear the effect of OAM affecting to a basic process of the ICS by numerical calculation and experiment.

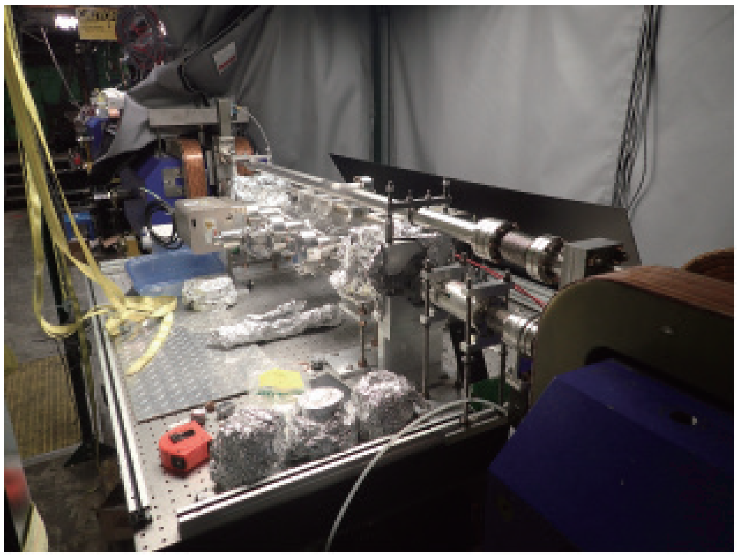
What are tasks?

- **Calculation of energy, scattering cross section of the gamma rays when the electron and/or laser photon are carrying OAM.**
- **Generation and experimental verification of gamma-rays carrying OAM.**
- **Development of twisted electron beam with the energy of MeV and GeV range.**
- **Basic research using a high energy electrons and gamma-rays carrying OAM.**

Vortex gamma ray generation at JLab

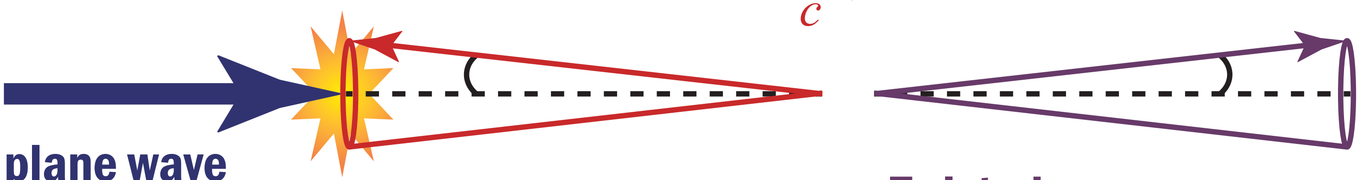


Compton polarimeter at Hall A or C or Hall D?



pw electron × twisted laser

Twisted laser $\vec{k} = \frac{\omega}{c}(\sin\theta_k \cos\phi_k, \sin\theta_k \sin\phi_k, \cos\theta_k)$

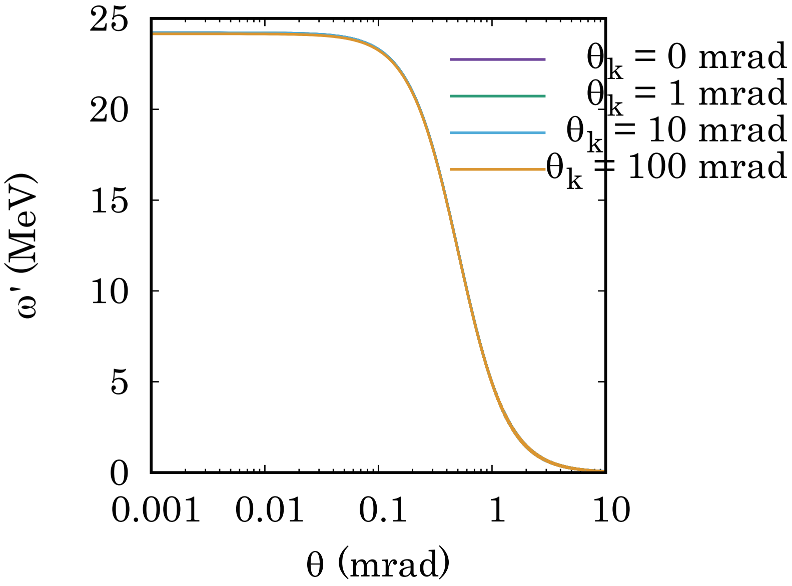


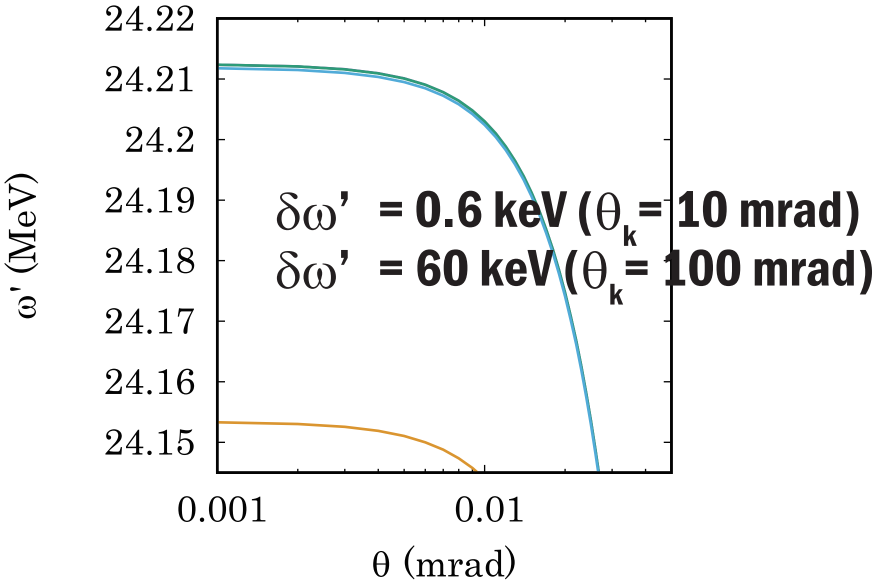
plane wave electron beam

$\vec{p} = p(0,0,1)$

Twisted gamma-rays

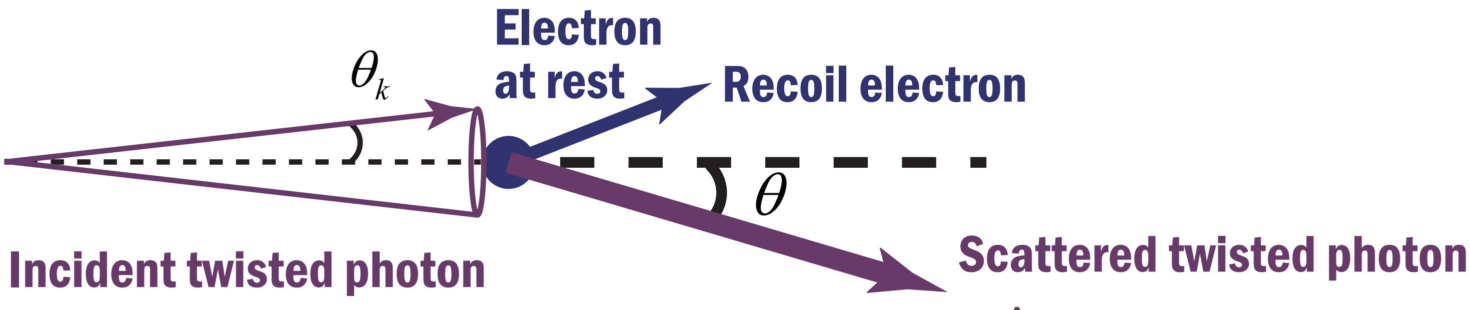
$\vec{k}' = \frac{\omega'}{c}(\sin\theta' \cos\phi', \sin\theta' \sin\phi', \cos\theta')$





U. D. Jentschura and V. G. Serbo, Phys. Rev. Lett. 106 (2011) 013001.

Compton scattering of twisted photon

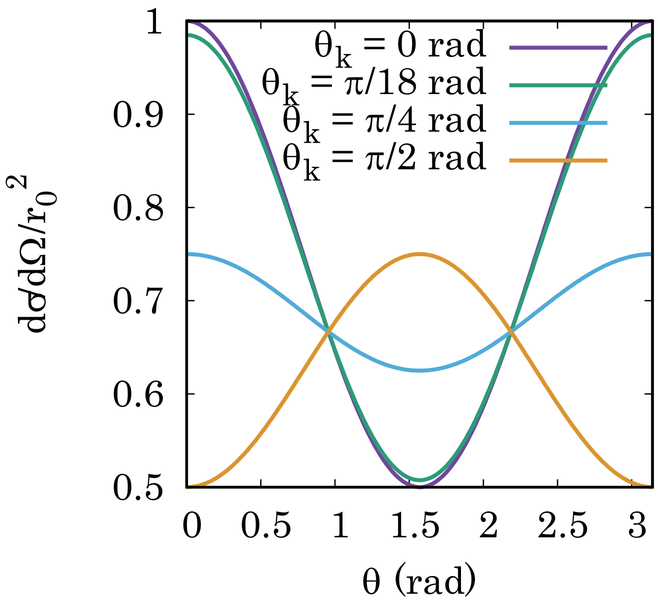


$$\vec{k} = \frac{\omega}{c}\left(\sin\theta_k \cos\phi_k, \sin\theta_k \sin\phi_k, \cos\theta_k\right)$$

Cross section

$$\frac{\mathrm{d}\sigma}{\mathrm{d}\Omega} = \frac{r_0^2}{4}\left\{\left(1+\cos^2\theta_k\right)\left(1+\cos^2\theta\right) + 2\sin^2\theta_k \sin^2\theta\right\}$$

$$\frac{\hbar\omega}{m_e c^2} << 1$$ **Thomson scattering**



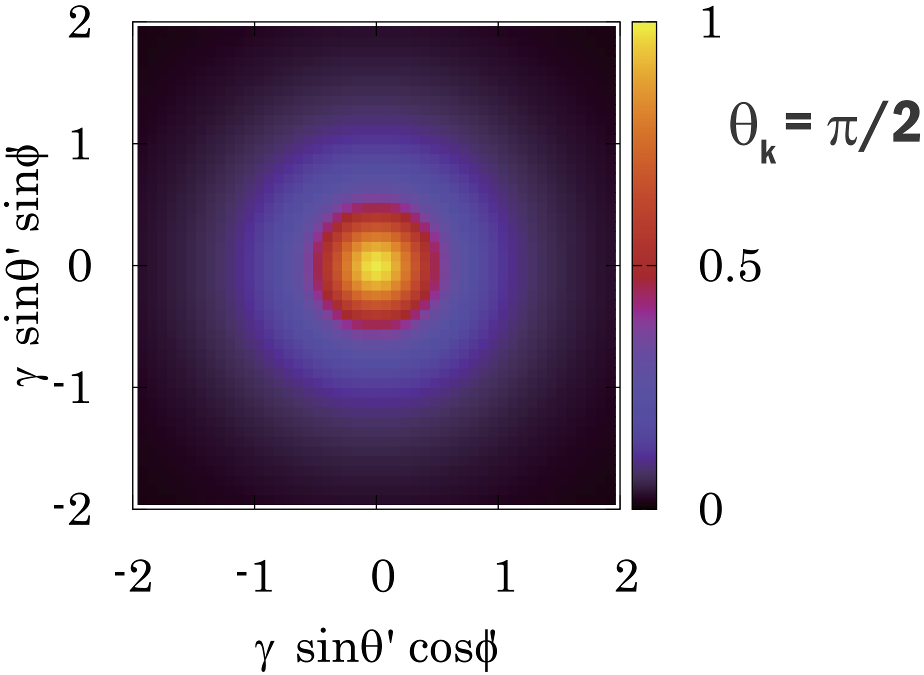
S. Stock et al., Phys. Rev. A 92 (2015) 013401.

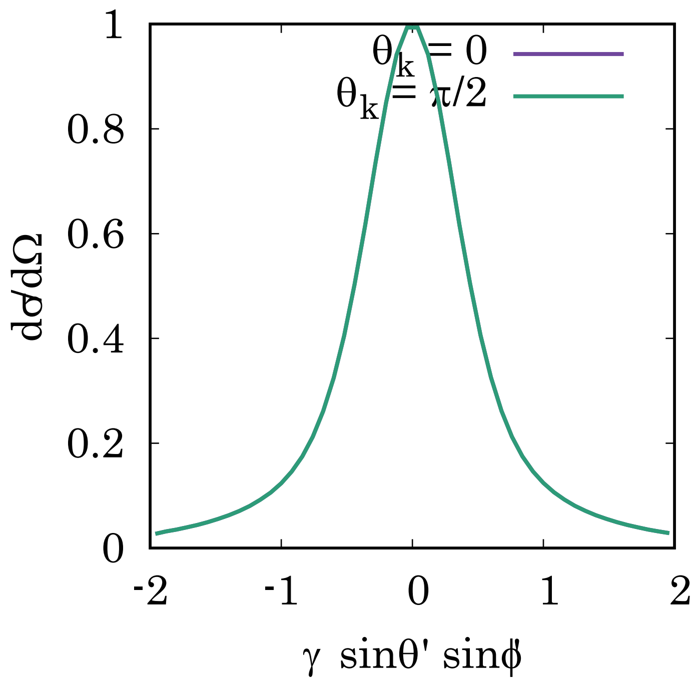
pw electron × twisted laser

Cross section

$$\frac{d\sigma}{d\Omega} = \frac{1}{\gamma^2(1-\beta\cos\theta')^2}\frac{r_0^2}{4}\left\{\left(2-\sin^2\theta_k^{\mathrm{ER}}\right)\left(2-\cos^2\theta\right)+2\sin^2\theta_k^{\mathrm{ER}}\sin^2\theta\right\}$$

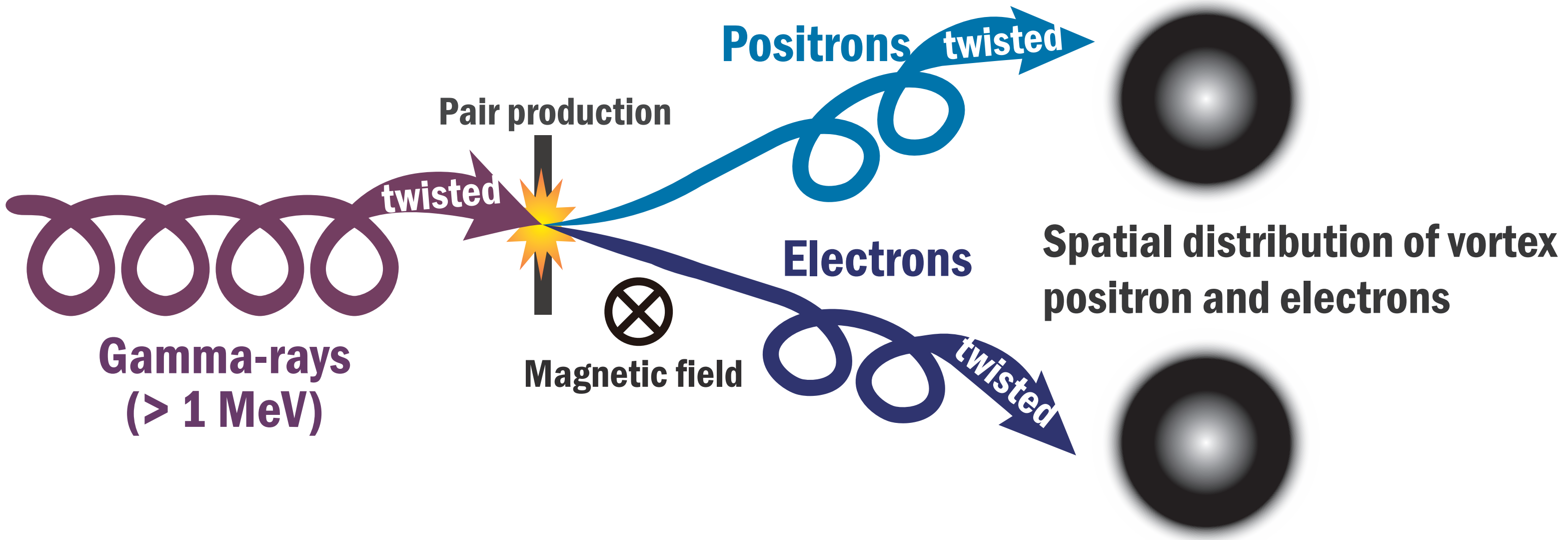
$$\sin\theta_k^{\mathrm{ER}} = \frac{\sin\theta_k}{\gamma(1+\beta\cos\theta_k)} \qquad \sin\theta = \frac{\sin\theta'}{\gamma(1-\beta\cos\theta')}$$





How to measure vortex gamma ray?

Measuring the twistedness of electron and positron produced from vortex gamma ray via pair production?



Tasks

- **Geant 4 simulation to produce the vortex gamma ray.**

  Imaging what will happen to the gamma ray and thinking how to detect the vortex gamma ray.

  Please tell me how to use Geant 4 and give me sample files.

- **Laser**

  Do you have or do you know the laser nobody uses?

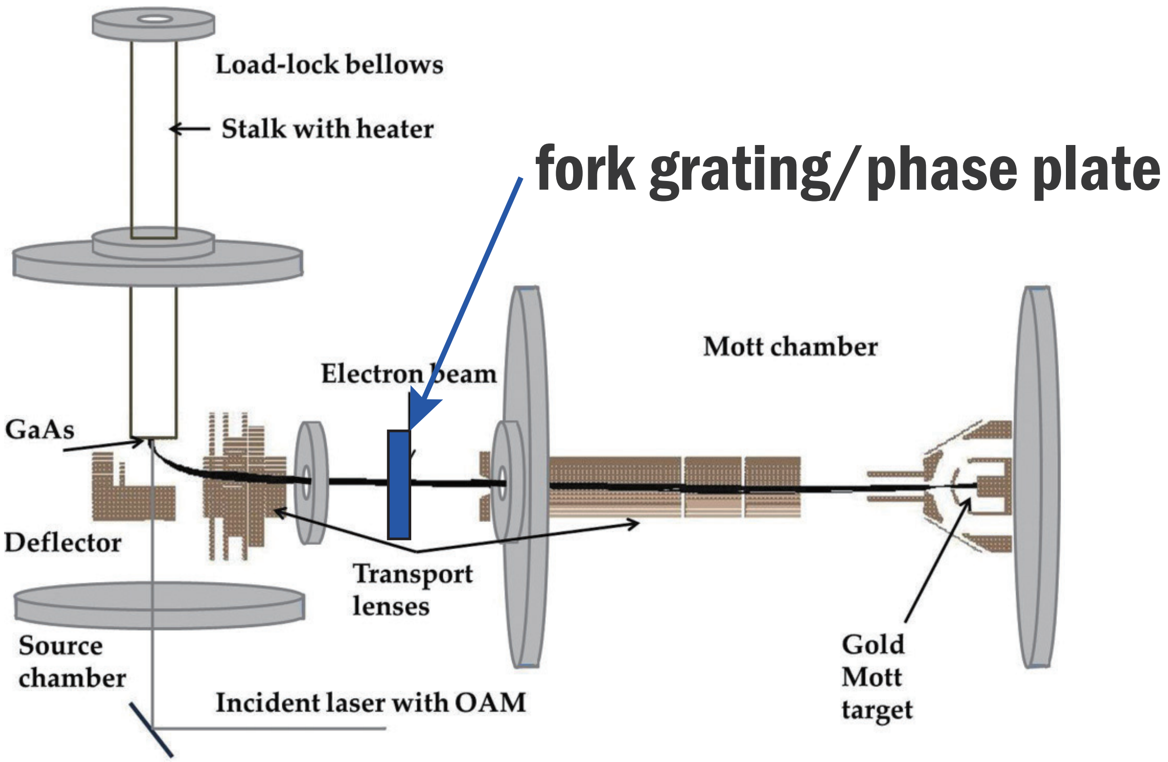
- **Candidate place to do the ICS experiment**

  Compton polarimeter at Hall A or C?
  Constracting a new ICS at Hall D?

Back up slides

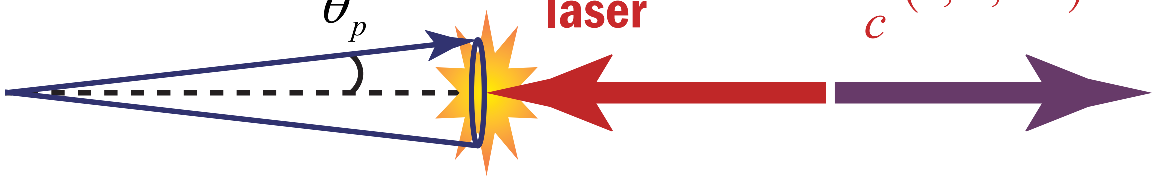
Calculation of ICS between vortex electron and plane wave laser appears in the next few slides.

Vortex electron generation at JLab



R&D of vortex electron measurement and acceleration at CEBAF injector

Twisted electron × pw polarized laser



Gamma-ray energy

$$\omega' = \frac{4\gamma^2\omega}{1+\gamma^2\chi^2}$$

$$\chi^2 = \theta_p^2 + \theta'^2 - 2\theta_p\theta'\cos(\phi_p - \phi') = (\theta_p \mp \theta')^2$$

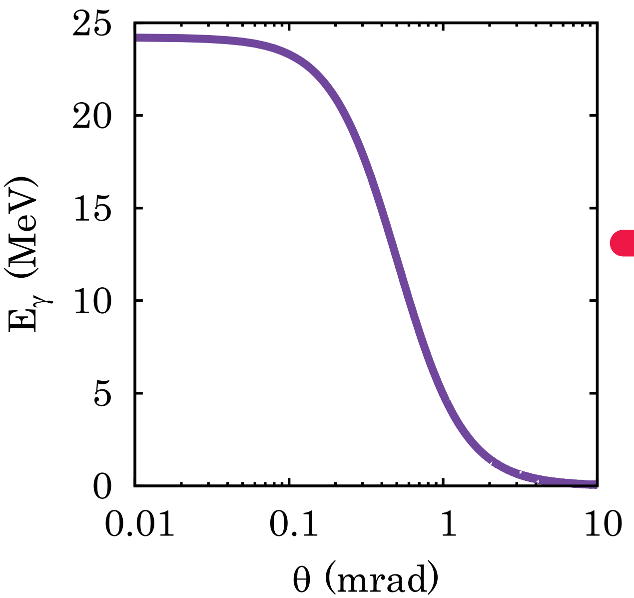
θ_p : Opening angle of the twisted electron $\qquad \tan\theta_p = \frac{|\vec{p}_\perp|}{p_z}$

D. Seipt et al., Phys. Rev. A 90 (2014) 012118.

Twisted electron × pw polarized laser

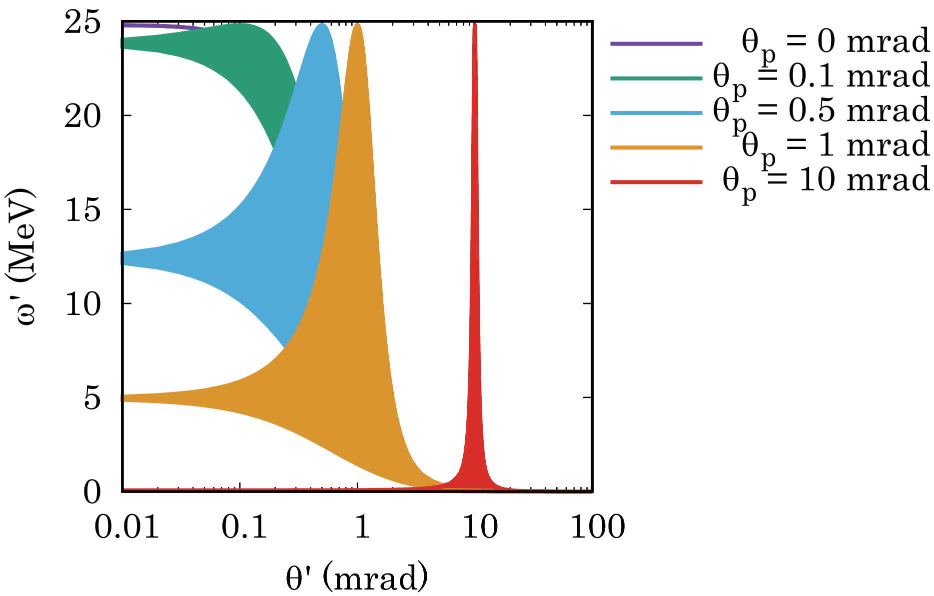
Gamma-ray energy

Plane wave electron



Twisted electron

$\gamma = 2000$



Energy spectrum depending on the scattering angle and opening angle can be measured with a collimator.

Twisted electron × pw polarized laser

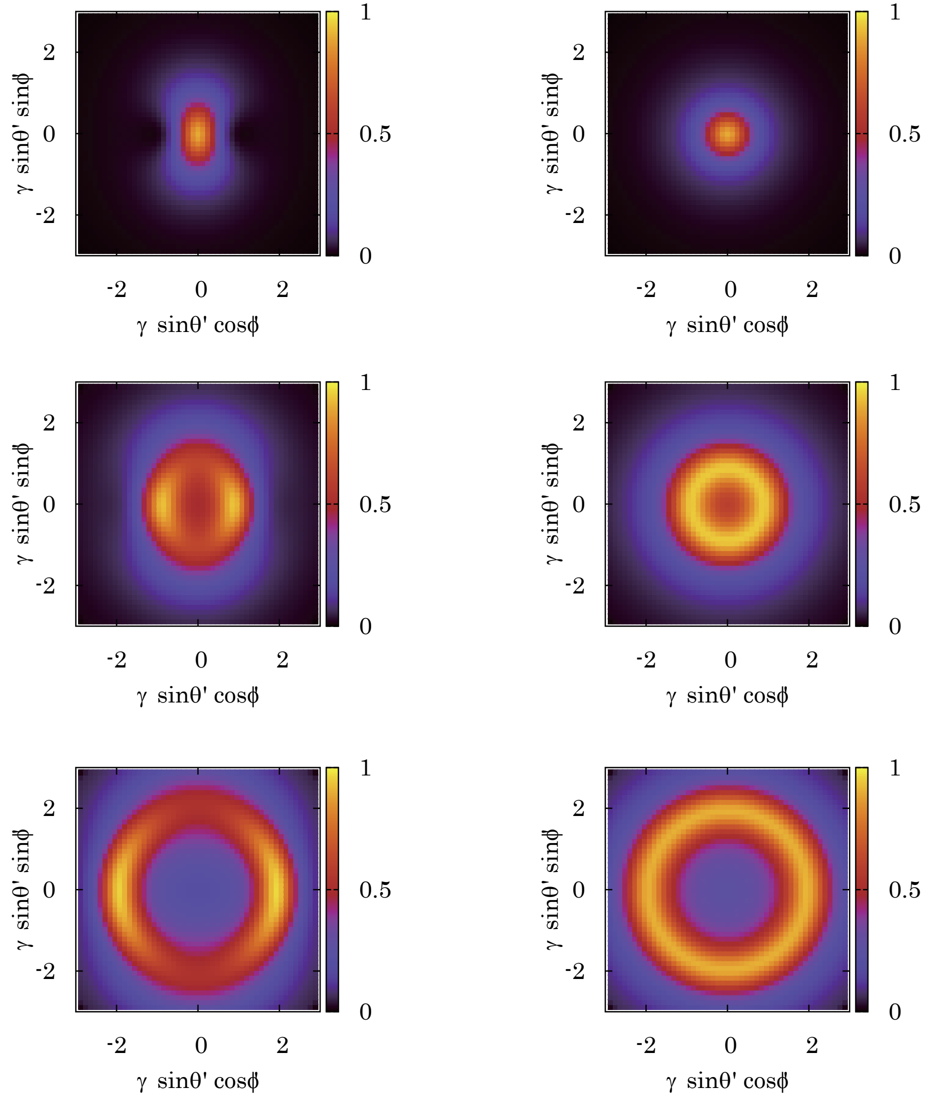
Spatial distribution

Linearly polarized laser | **Circularly polarized laser**

$\theta_p = 0.1$ mrad

$\theta_p = 0.5$ mrad

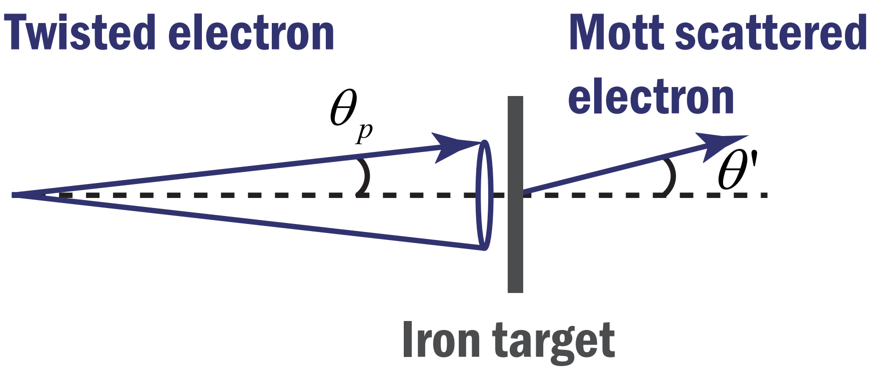
$\theta_p = 1$ mrad

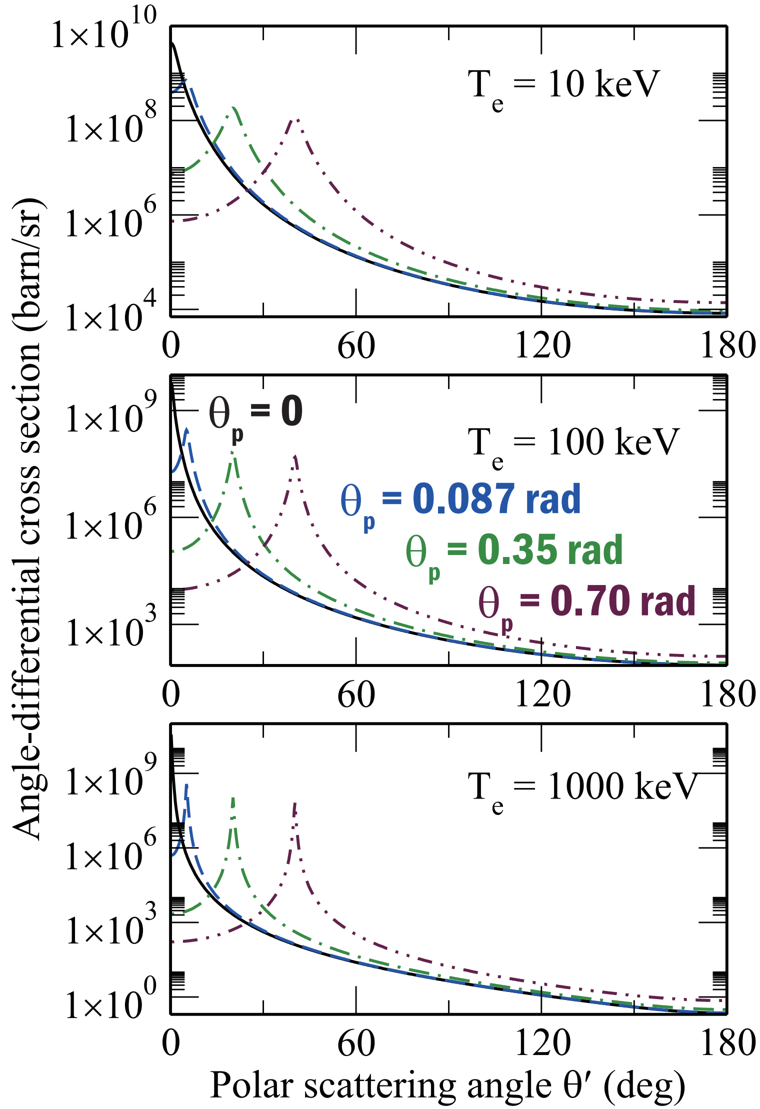


If the opening angle is large, it can be measured by an imaging detector.

Scattering of twisted electrons by atoms

$$\vec{p} = p\left(\sin\theta_p \cos\phi_p, \sin\theta_p \sin\phi_p, \cos\theta_p\right)$$





Scattered pattern of twisted electrons differ from that of plane wave electron.

Peak intensity appears at the same angle of the opening angle.

V. Serbo et al., Phys. Rev. A 92 (2015) 012705.