



**The Abdus Salam
International Centre for Theoretical Physics**



2037-9

Introduction to Optofluidics

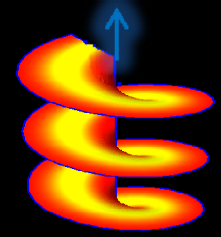
1 - 5 June 2009

Generation of needle beams and manipulation of light beam shapes by using birefringent plates with topological charge

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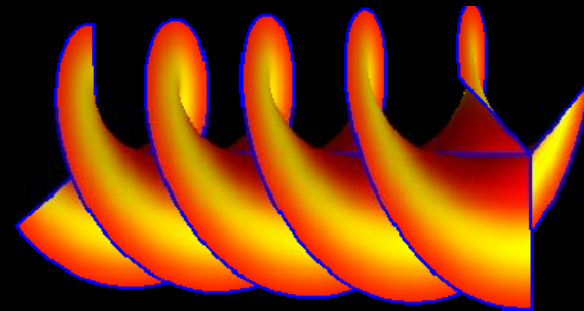


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Generation of "needle" beams and manipulation of light beam shapes by using birefringent plates with topological charge

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Contents

- Introduction
- Spin and Orbital angular momentum of light.
- Interaction with matter.
- How can we create them?
- Birefringent plate with topological charge, “q-plate”.
- How is it working?
- Tuning of the q-plate.
- High efficient generation of HG beam and beam shapes controlling.
- Generation of radially polarized light beam.
- Needle beam.

introduction

$$|E\rangle = \sum_{k,p,s,l} C_{kpsl} |k\rangle \otimes |p\rangle \otimes |s\rangle \otimes |l\rangle$$

Wave Vector

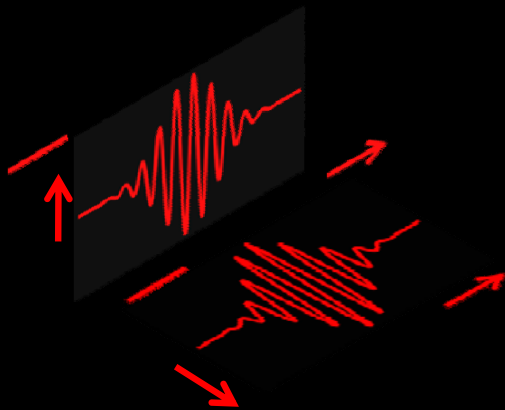
Radial index

Spin

OAM



Propagation direction



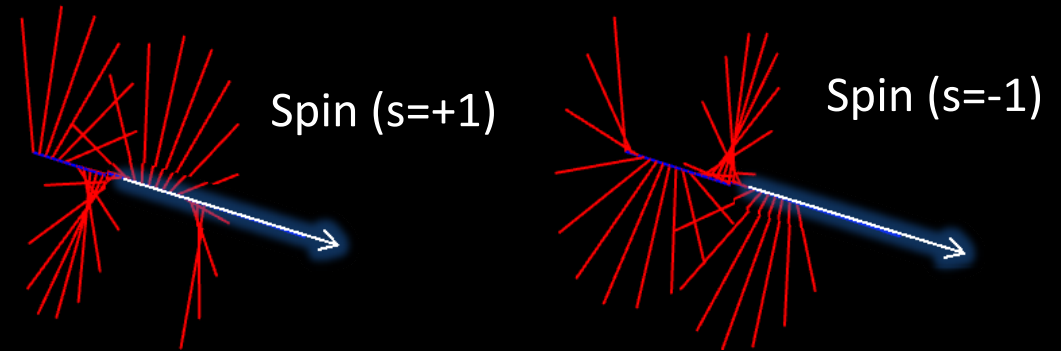
1. Radial index
2. OAM
3. Spin



SAM and OAM

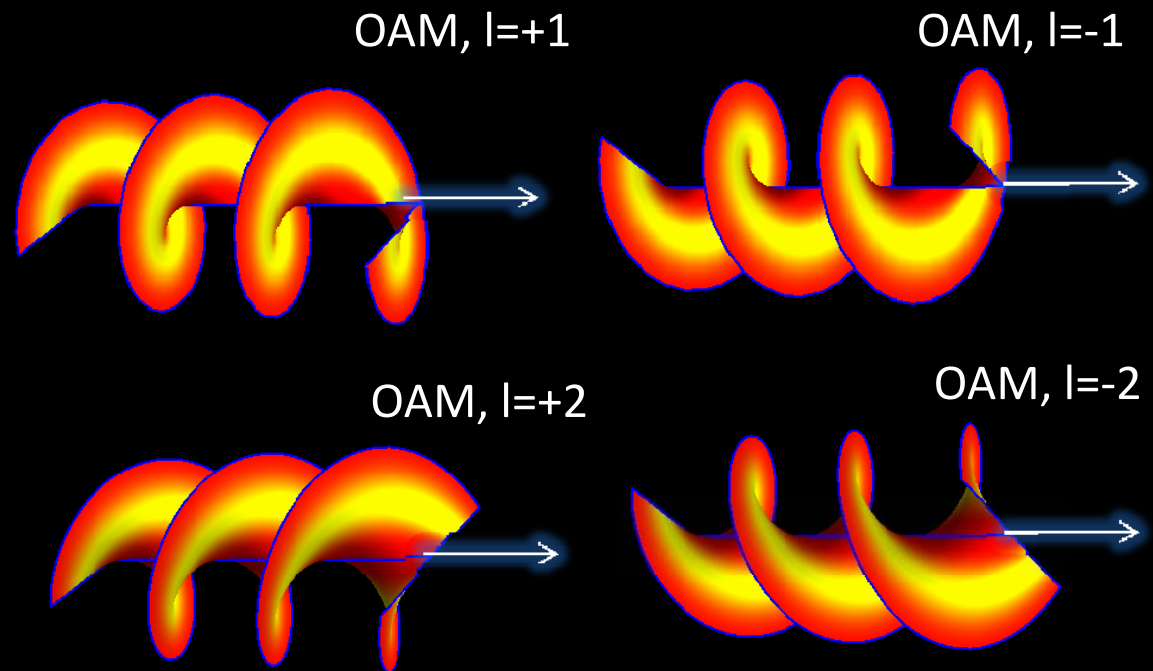
- SAM

Spin angular momentum may take two values of $s=-1$ and $s=+1$.



- OAM

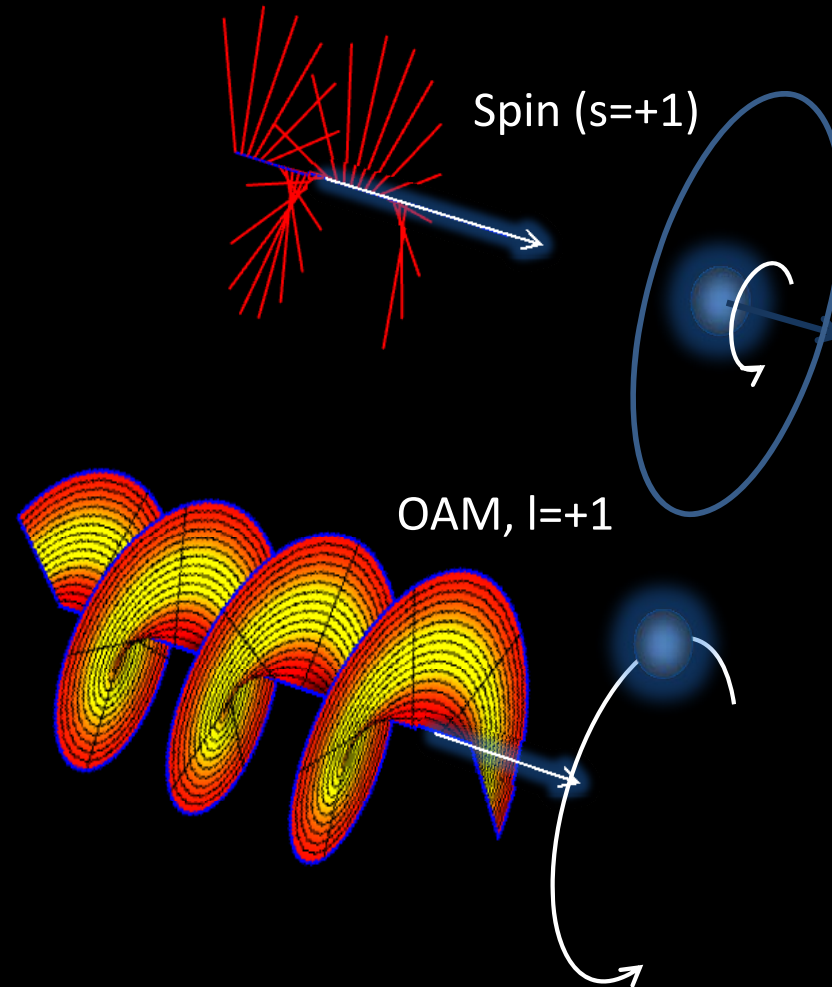
In the contrast, orbital angular momentum may take any of the infinite values $m=\dots-2,-1,0,1,2,\dots$.





What is the difference between SAM and OAM?

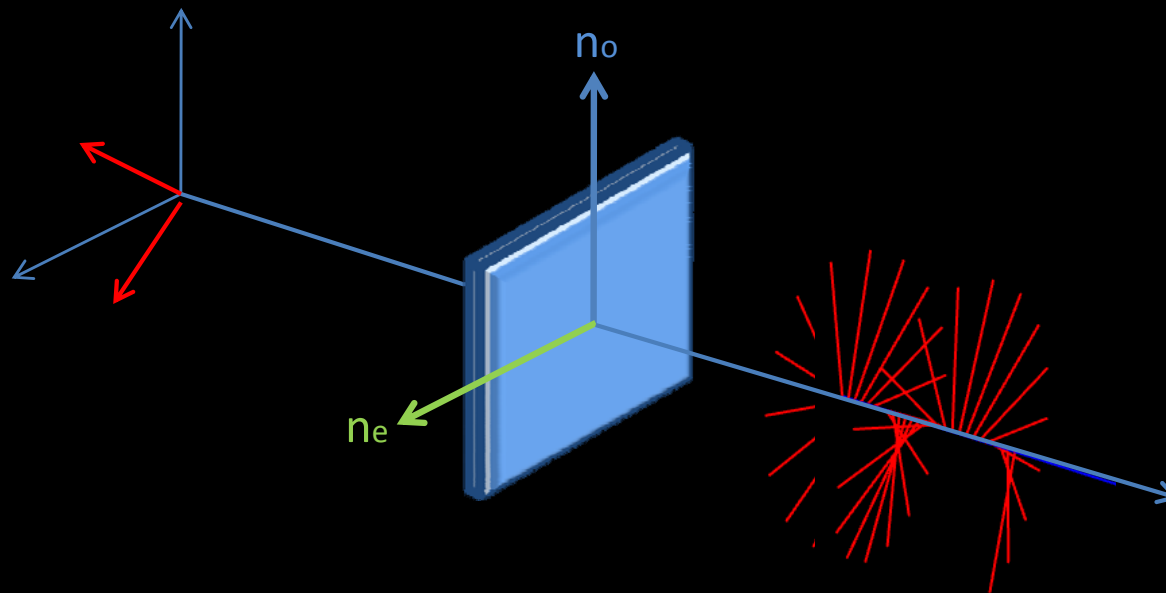
- SAM
- OAM





Creation of SAM

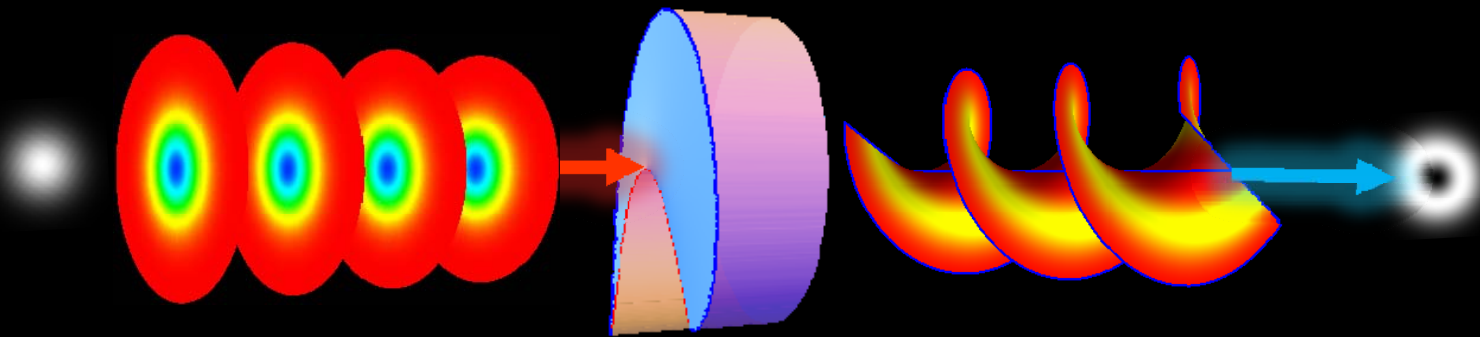
- By using an anisotropic (birefringent) medium (e.g., wave-plates)





Creation of OAM

Spiral Phase Plate



Other Methods

- Pitchfork hologram
- Spatial Light Modulator (SLM)
- Mode Converters (A couple of cylindrical lenses)
- Leach's interferometer

L. Allen et al, PRA, **45**, 8185 (1992)

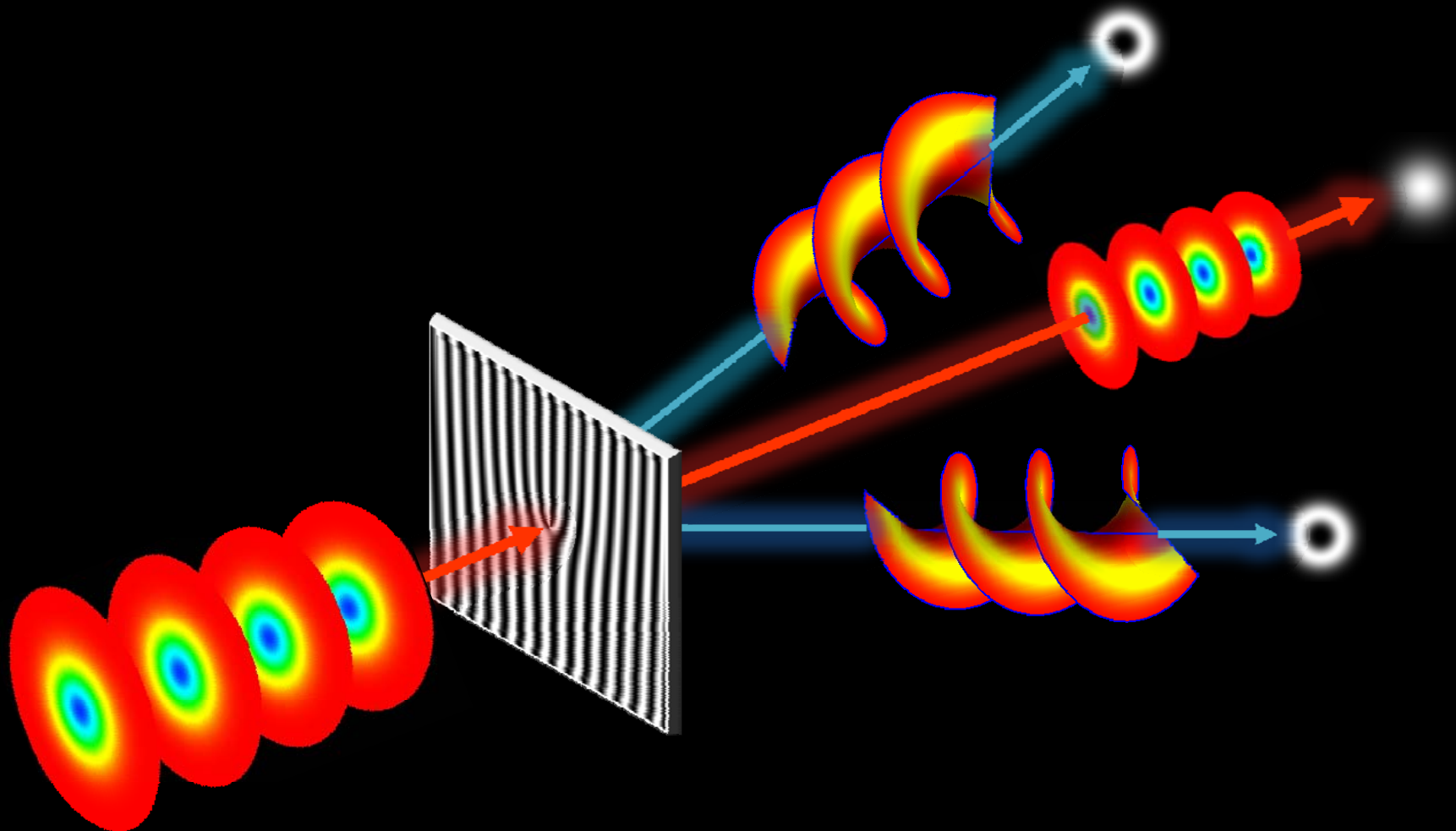
M. W. Beijersbergen et al., Opt. Com. **112**, 321 (1994)

J. Leach et al, PRL, **92**, 013601 (2004)



Creation of OAM

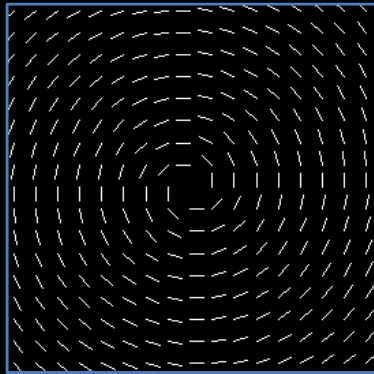
Pitch-fork Hologram



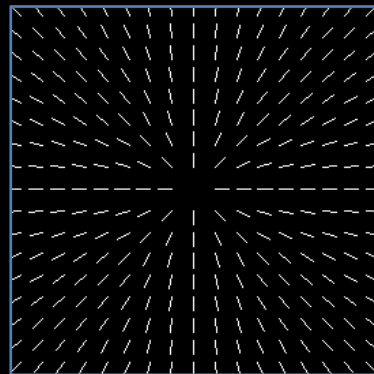


The "Q-Plate"

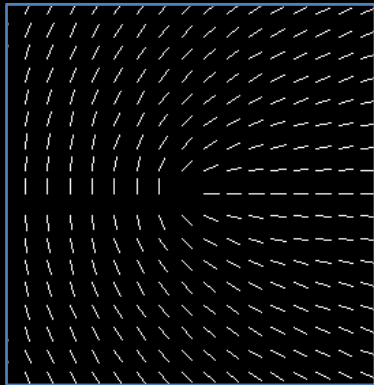
- "Q-Plate" is an optical device which made by Liquid Crystal for impinging OAM onto incident wave.



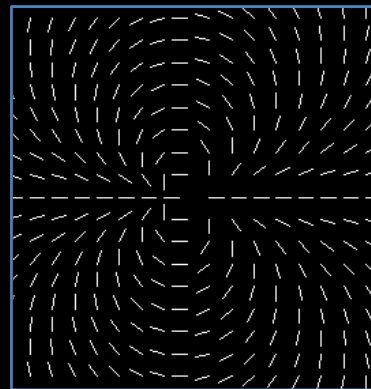
$$\alpha = \varphi + \frac{\pi}{2}$$



$$\alpha = \varphi$$

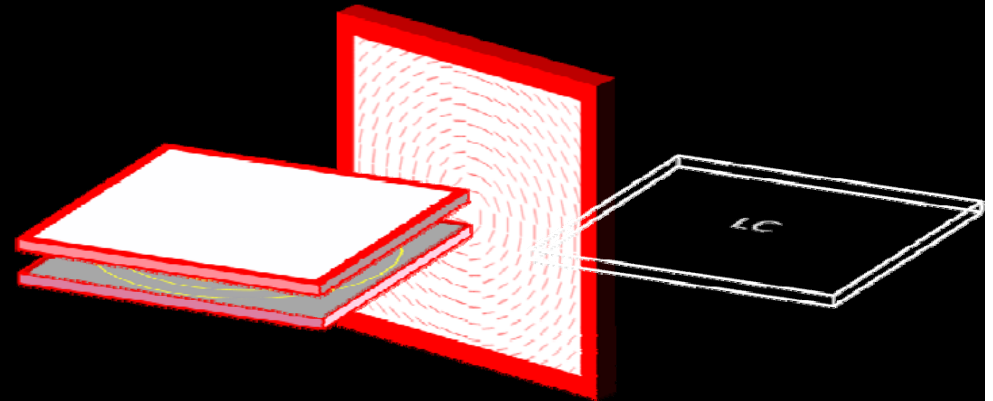
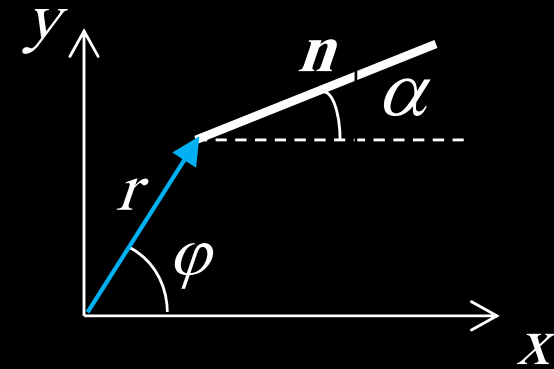


$$\alpha = \frac{1}{2}\varphi$$



$$\alpha = 2\varphi$$

$$\alpha = q\varphi + \alpha_0$$





The q-plate's action

$$\begin{aligned}
 M(x, y) &= \hat{R}(-\alpha) \cdot \begin{pmatrix} e^{i\delta} & 0 \\ 0 & e^{-i\delta} \end{pmatrix} \cdot \hat{R}(\alpha) \\
 &= \cos \frac{\delta}{2} \begin{pmatrix} 1 & 0 \\ 0 & 1 \end{pmatrix} + i \sin \frac{\delta}{2} \begin{pmatrix} \cos 2\alpha & \sin 2\alpha \\ \sin 2\alpha & -\cos 2\alpha \end{pmatrix}
 \end{aligned}$$

Let us now apply it to an **input left-circular** polarized plane wave:

$$\begin{aligned}
 M(x, y) \cdot \begin{pmatrix} 1 \\ i \end{pmatrix} &= \cos \frac{\delta}{2} \begin{pmatrix} 1 \\ i \end{pmatrix} + i \sin \frac{\delta}{2} \begin{pmatrix} 1 \\ -i \end{pmatrix} e^{i2\alpha} \\
 M(x, y) \cdot \begin{pmatrix} 1 \\ -i \end{pmatrix} &= \cos \frac{\delta}{2} \begin{pmatrix} 1 \\ -i \end{pmatrix} + i \sin \frac{\delta}{2} \begin{pmatrix} 1 \\ i \end{pmatrix} e^{-i2\alpha}
 \end{aligned}$$

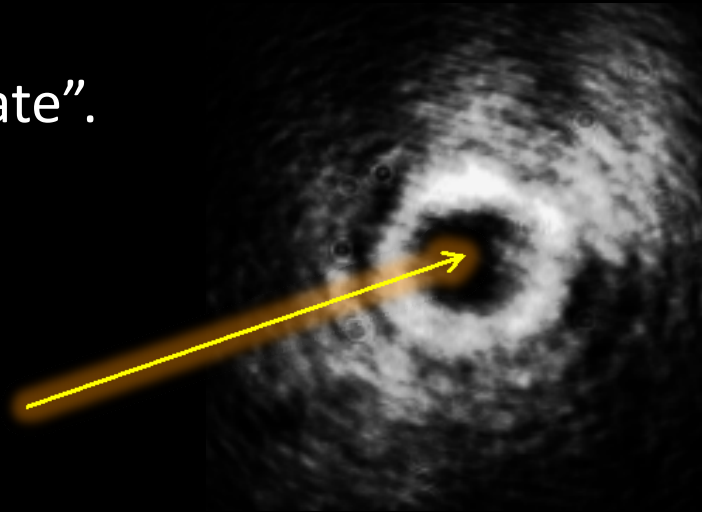
$i \xrightarrow{\text{for RCP}} -i$



What is the “Q-Plate”?

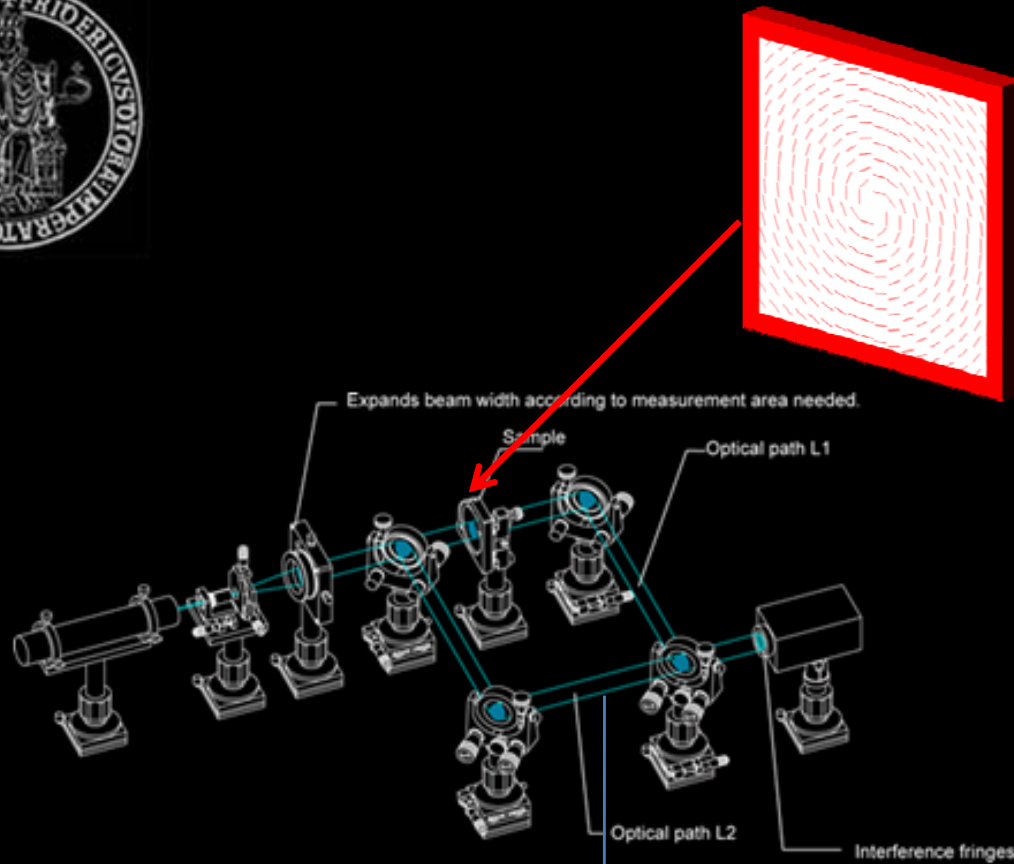
- Outgoing wave from a “1-plate”.
It is illuminated by TEM_{00}

Optical Vortex

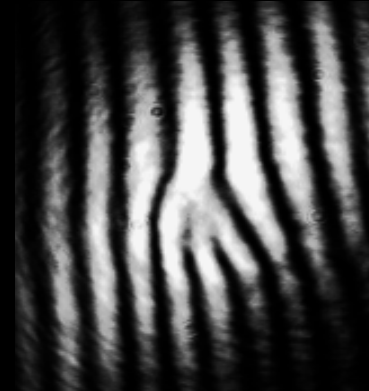


- A “1-plate” sandwiched between two crossed polarizers

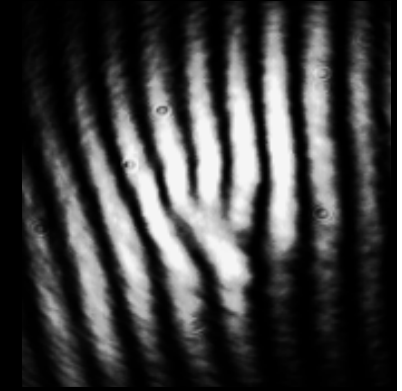




Left-circular input



Right-circular input



Left-circular input



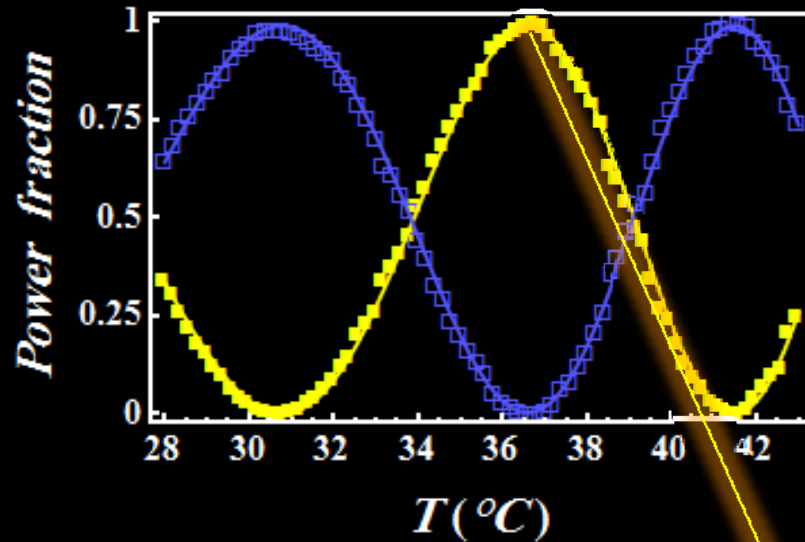
Right-circular input



By adding one lens to the system we will have:



Q-plate's tuning



$$\cos^2 \frac{\pi d \Delta n(T)}{\lambda}$$

Not converted part of beam

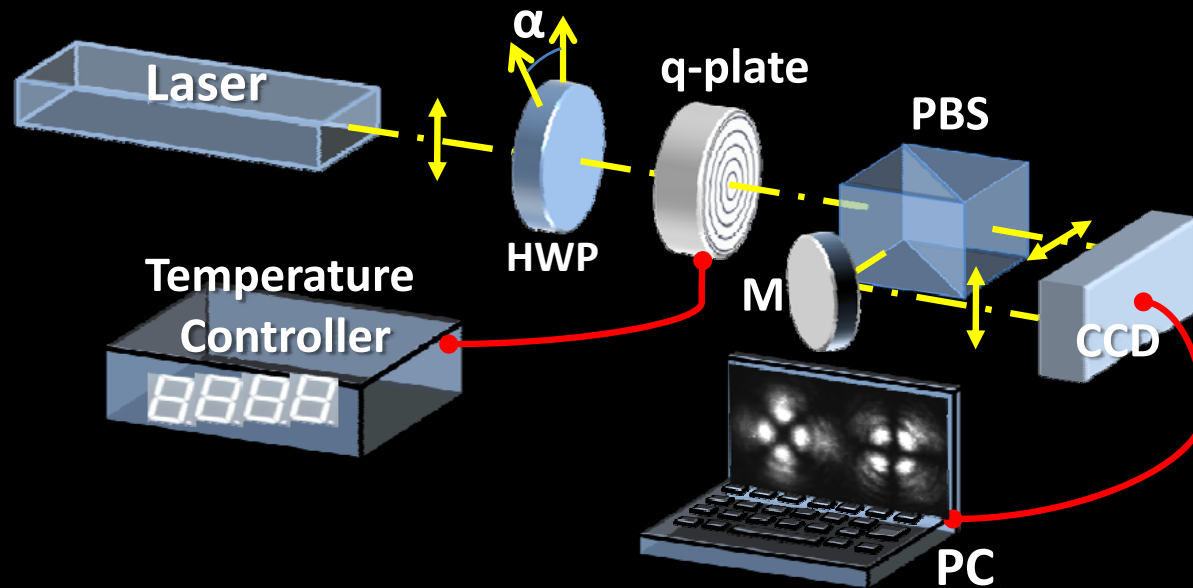
$$\sin^2 \frac{\pi d \Delta n(T)}{\lambda}$$

Converted part of beam

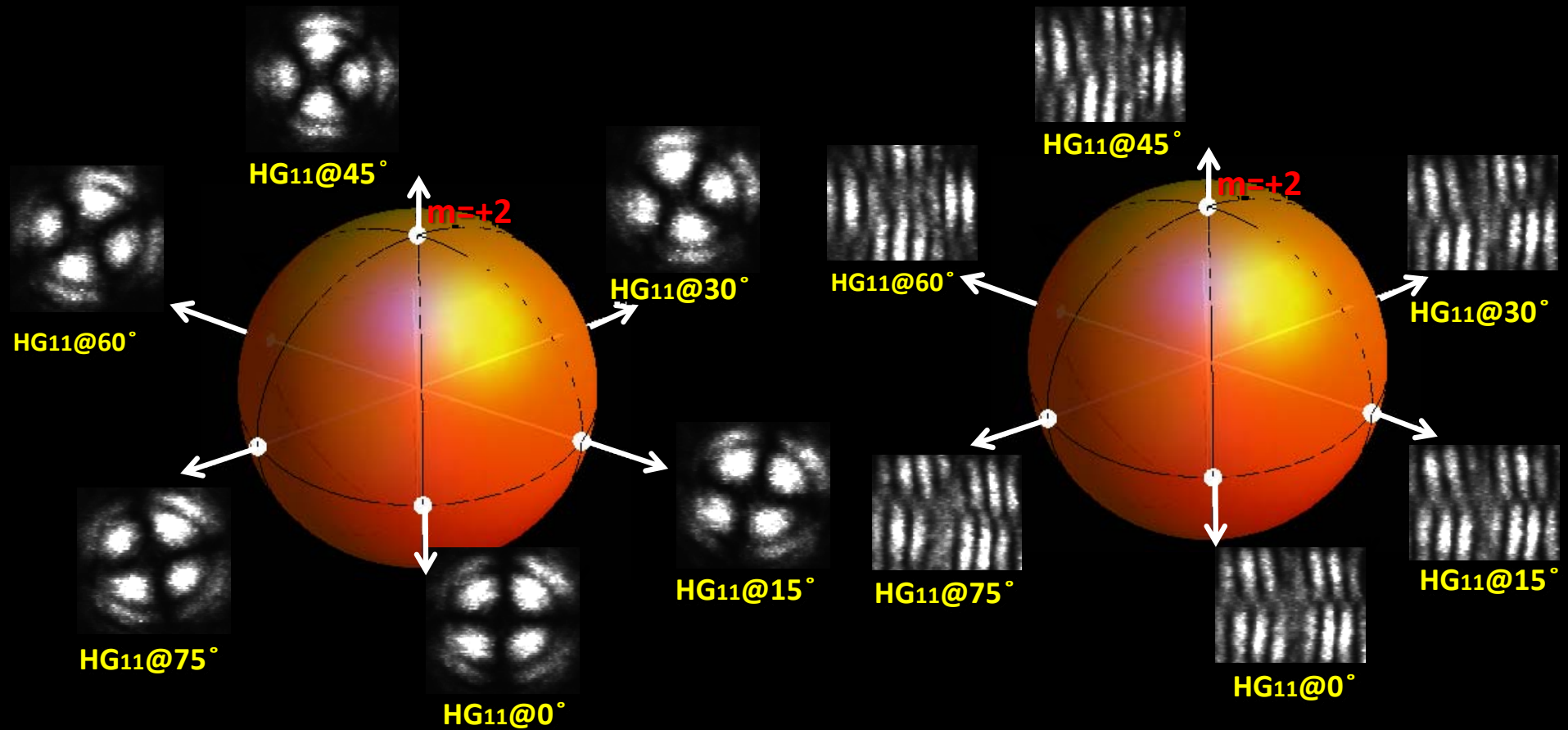
$$\eta = 97\%$$



Generation of HG modes

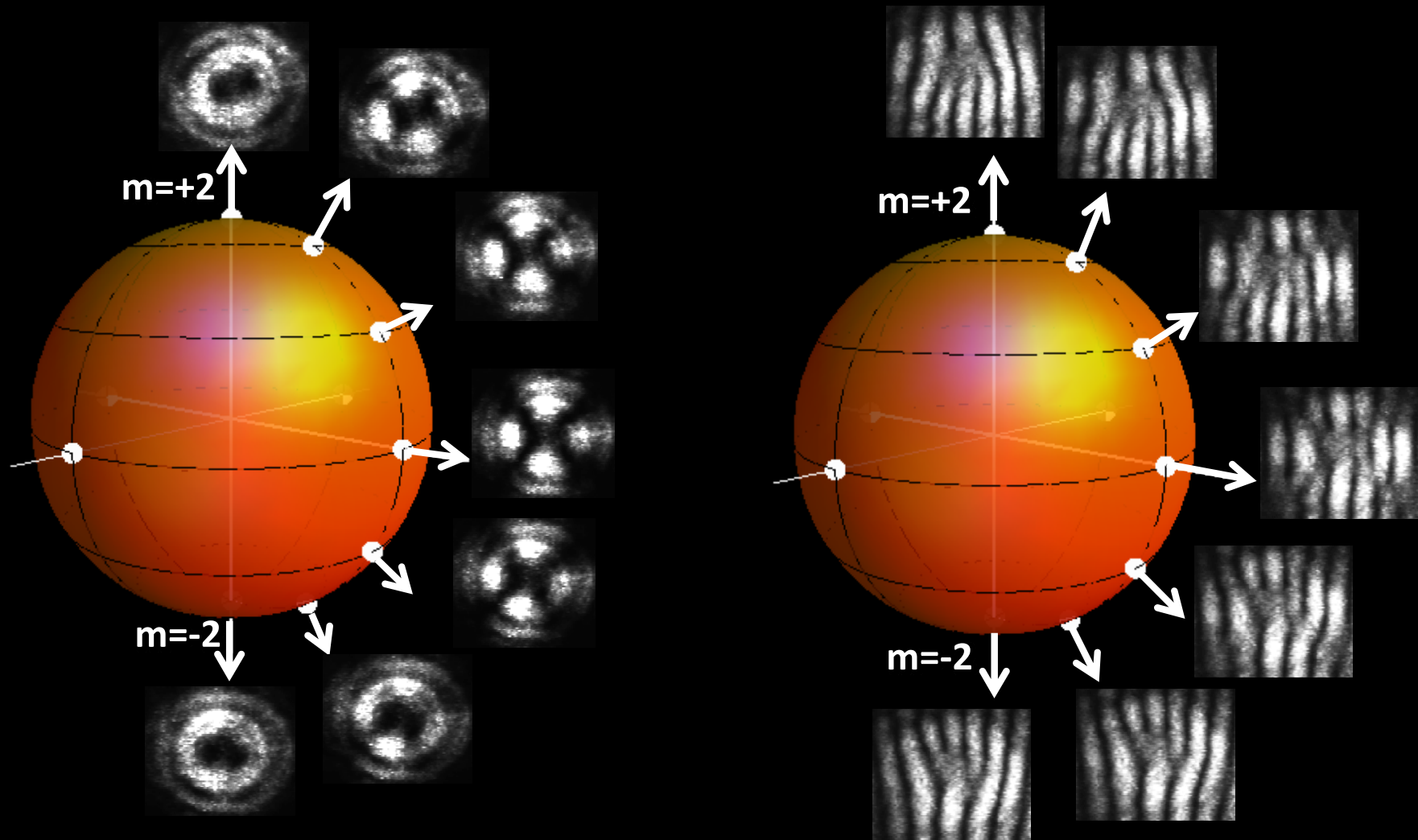


Generation of HG modes



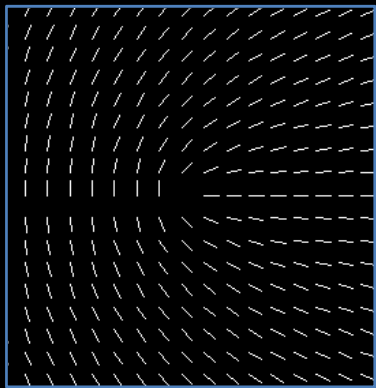
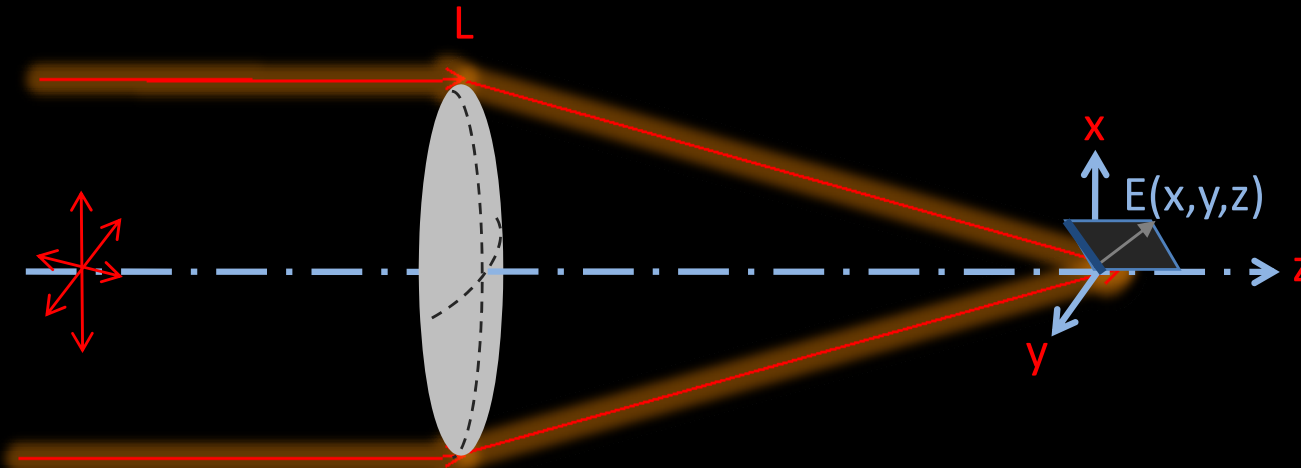


Generation of LG and HG modes

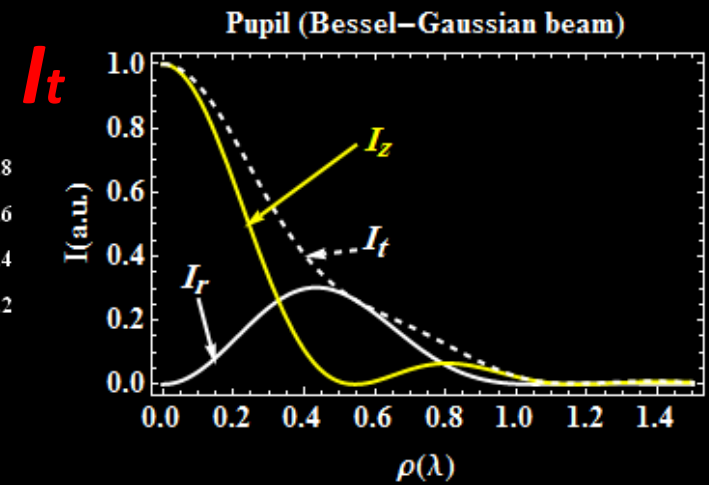
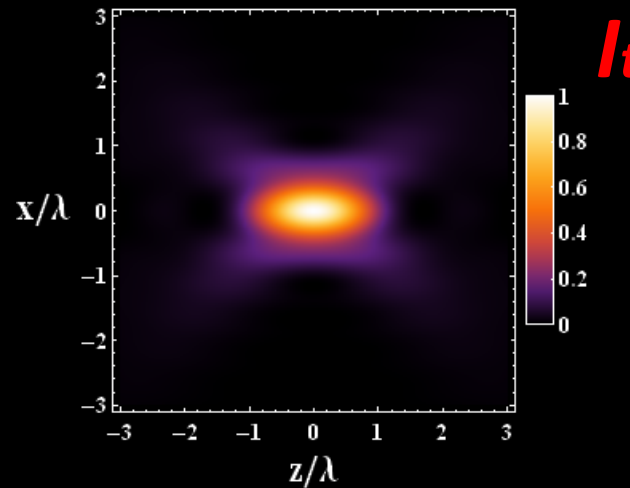




Radially polarized beam under strong focusing

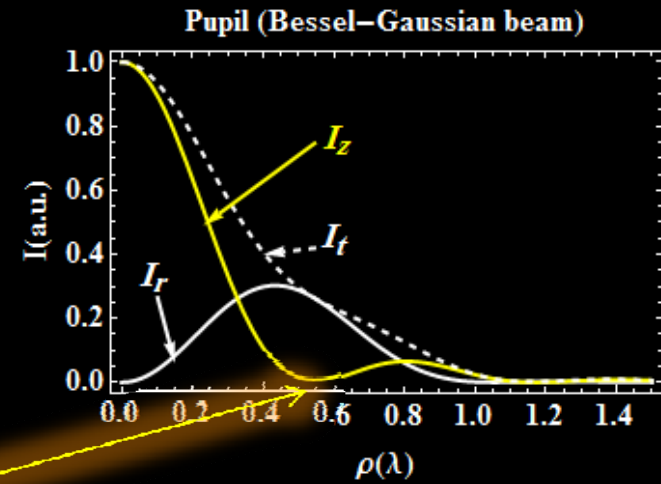
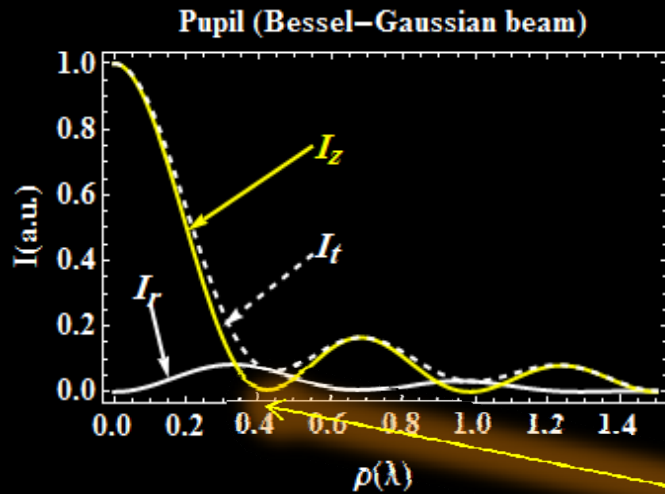
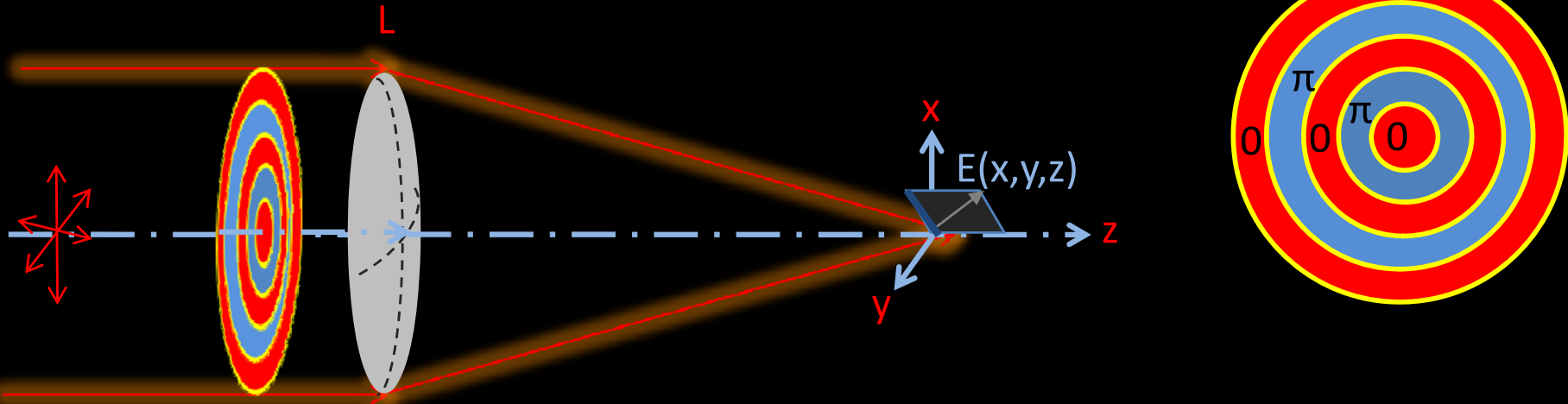


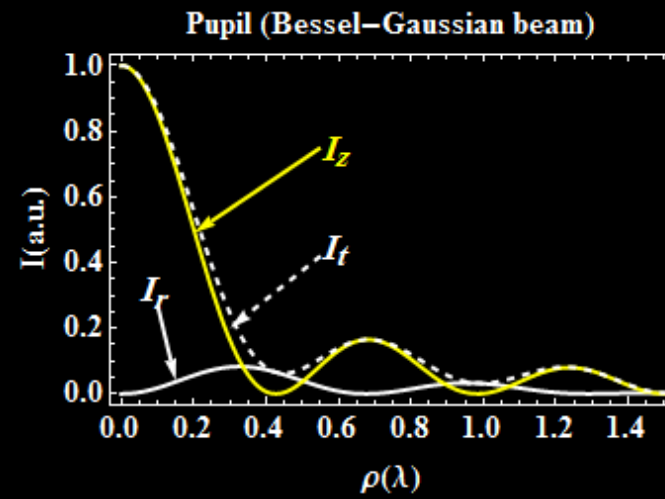
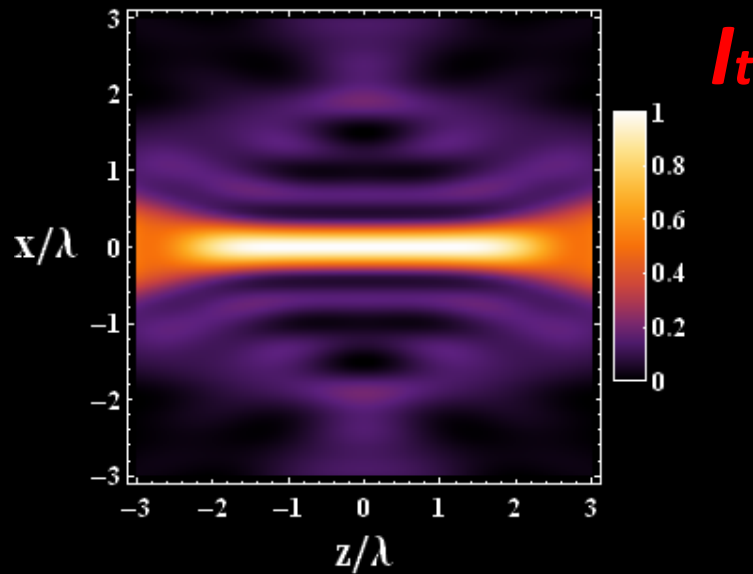
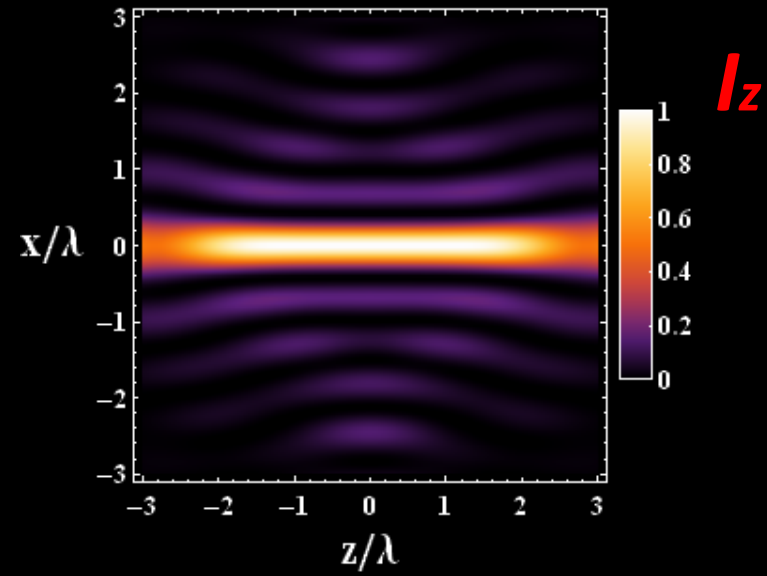
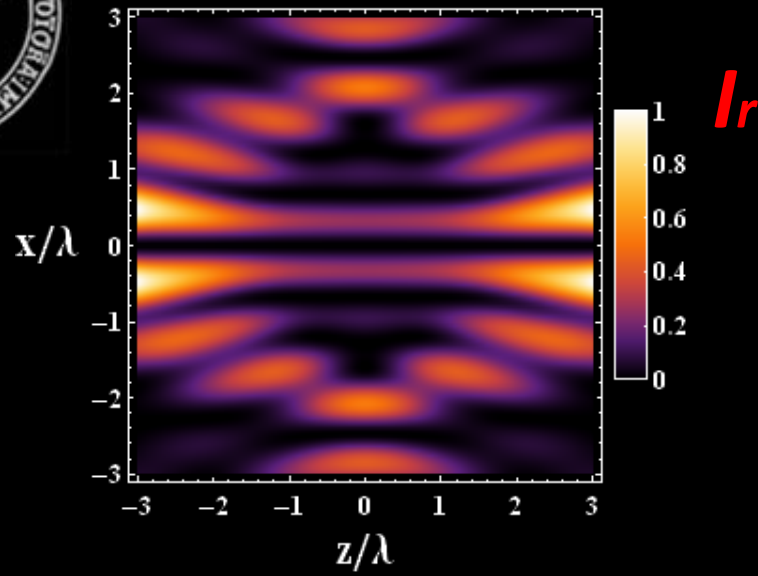
$$\alpha = \frac{1}{2}\varphi$$

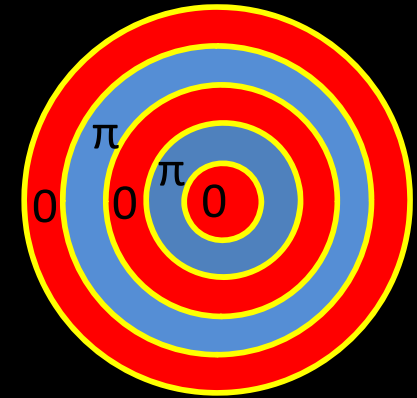
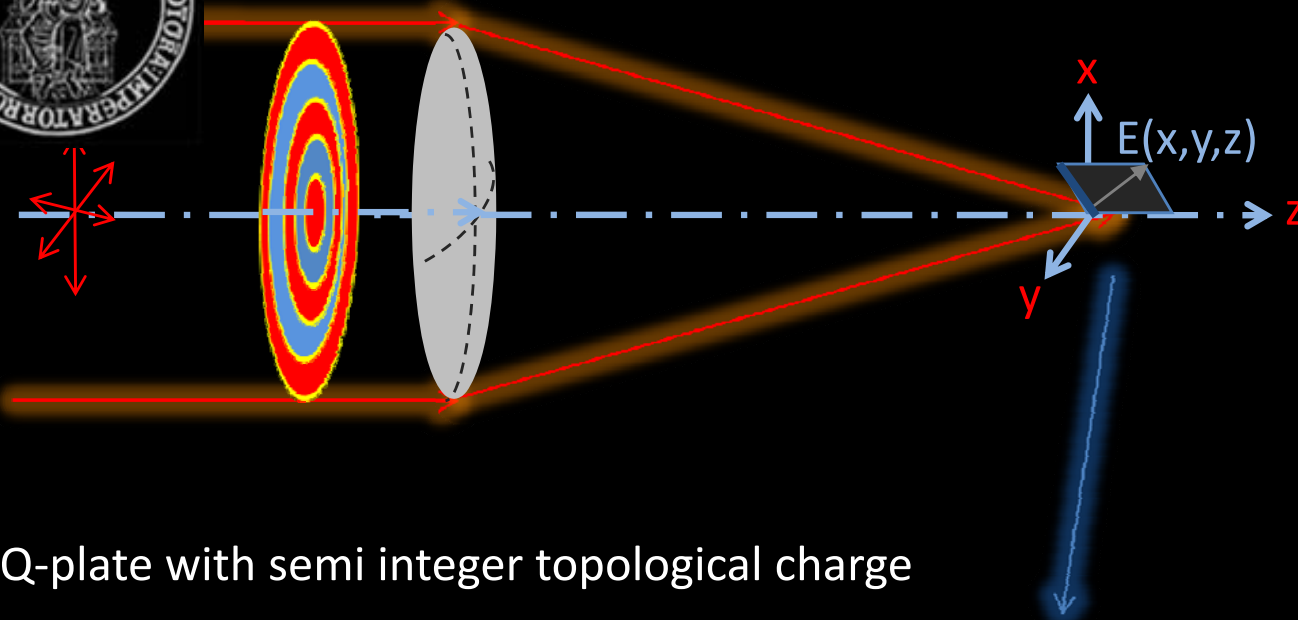




Radially polarized beam under strong focusing of a system of High NA lens and a binary phase mask

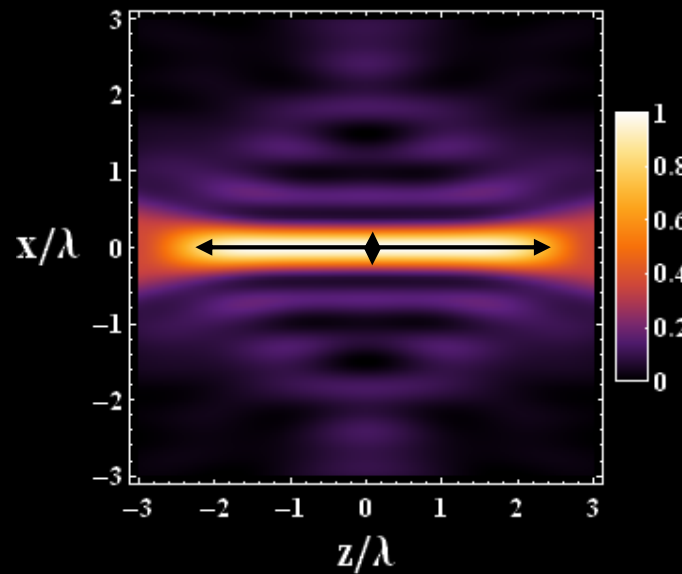




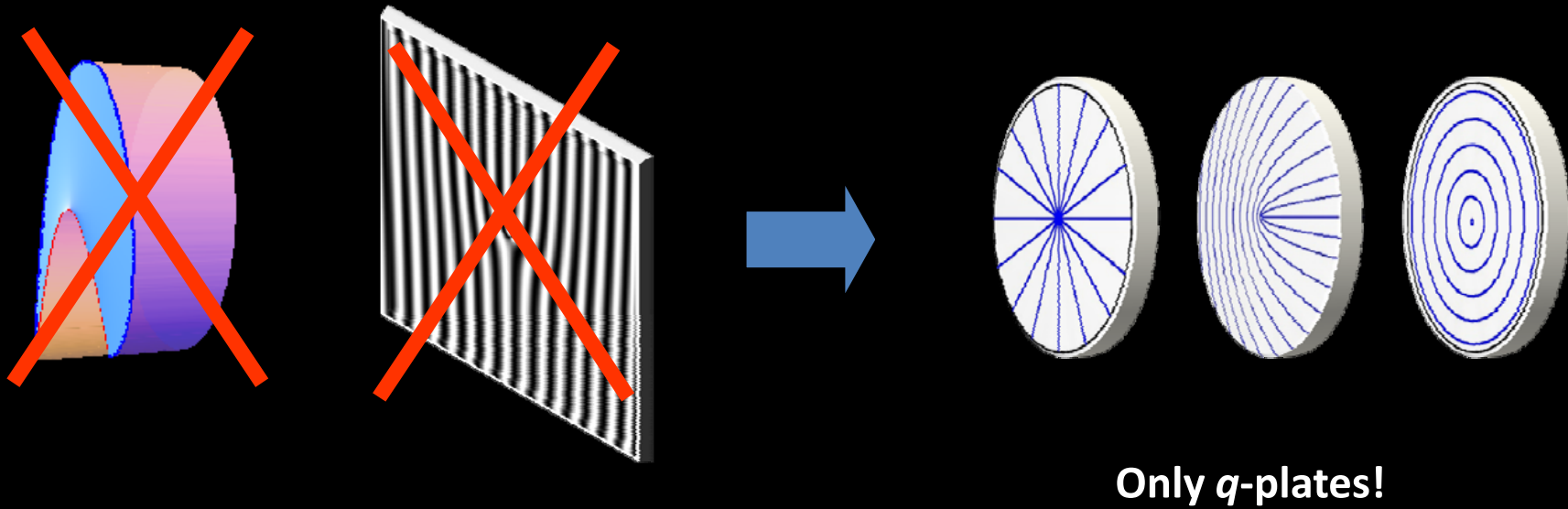


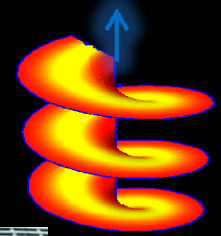
1. SLM
2. Hologram

Q-plate with semi integer topological charge



Conclusion





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Thank you for your attention.