Spatial Profile of the Squeezed Quantum Noise Generated and Modified by Resonant Atomic Ensembles

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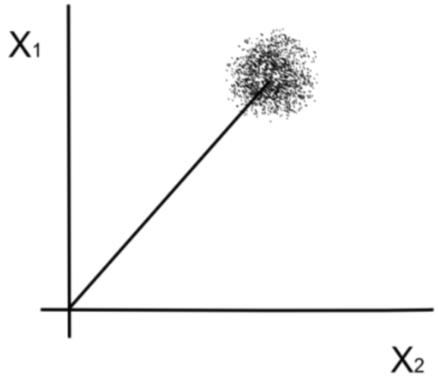
Squeezed State

Quantum Fluctuations in Light field:

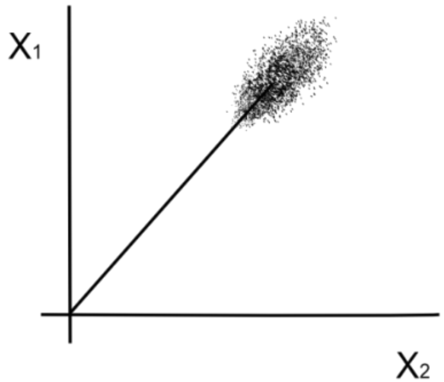
$$E(\phi) = |a|e^{-i\phi} = |a|sin(\phi) + i|a|cos(\phi) = X_1 + iX_2$$



Coherent State
Standard Quantum Limit

$$\delta X_1 = \delta X_2$$

$$\delta X_1 \delta X_2 = \frac{1}{4}$$



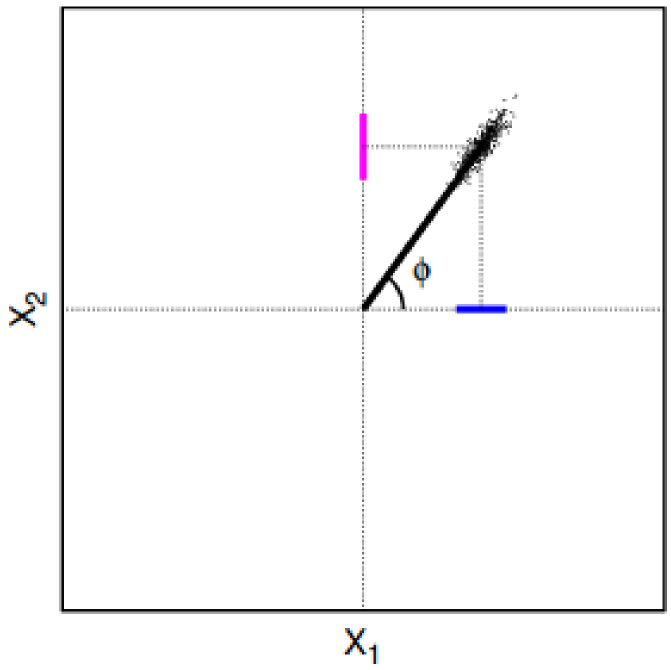
Squeezed State
Squeezed Quantum Noise

$$\delta X_1 \neq \delta X_2$$

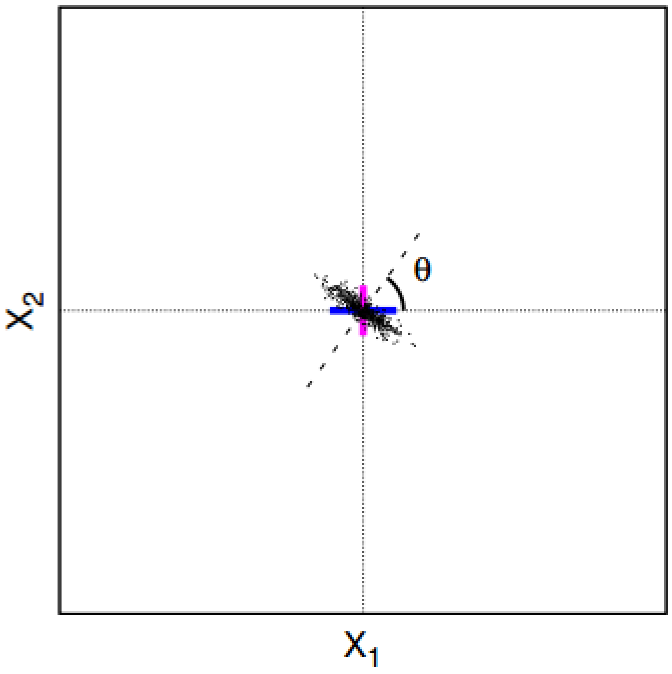
$$\delta X_1 \delta X_2 \geq \frac{1}{4}$$

Squeezed Vacuum State

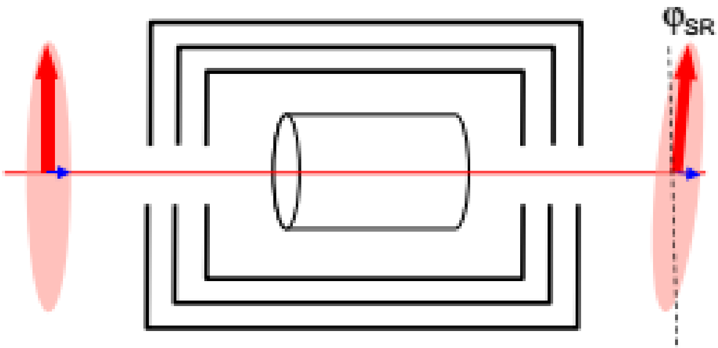
Squeezed State

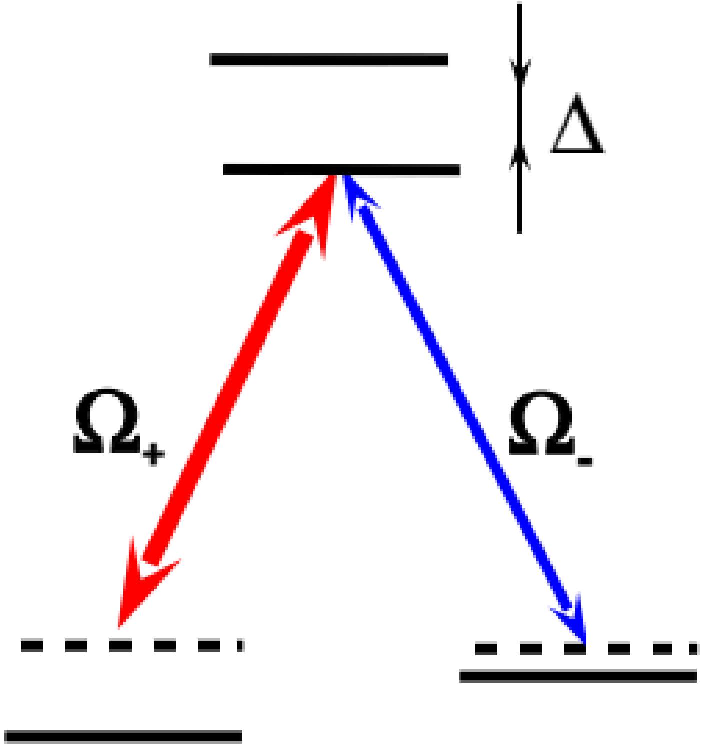


Squeezed Vacuum State



Polarization Self-Rotation

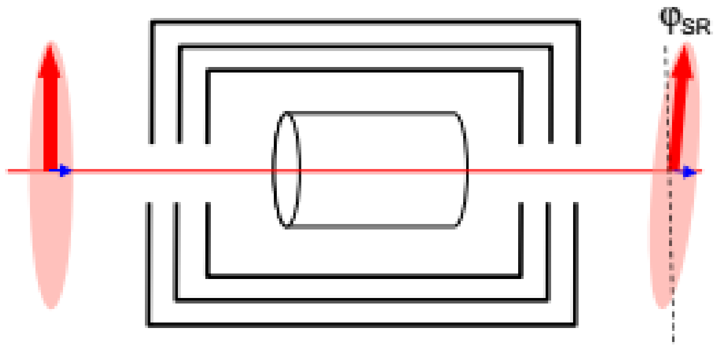


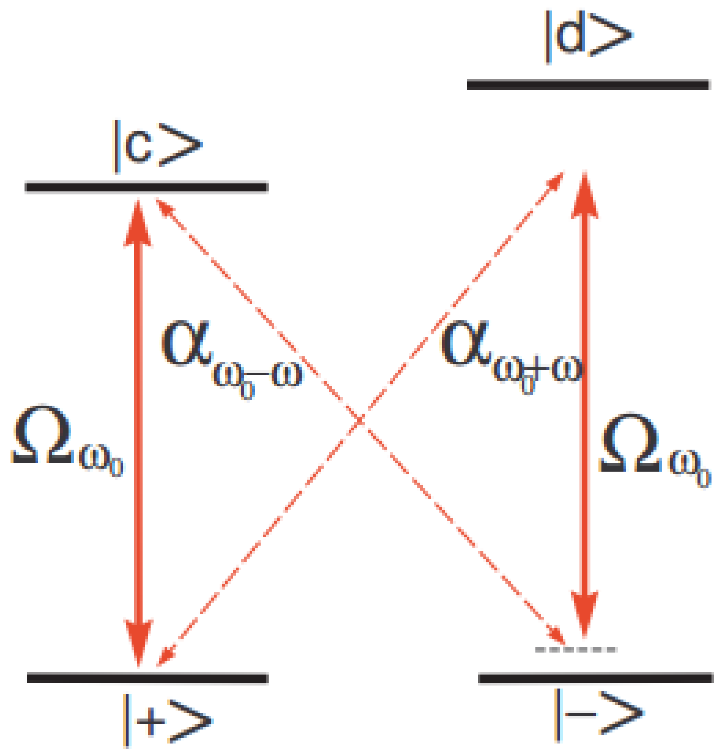


A.B. Matsko et al., PRA 66, 043815 (2002):
theoretically prediction of 4-6 dB noise suppression

$$a_{out} = a_{in} + \frac{igL}{2}\left(a_{in}^{\dagger} - a_{in}\right)$$

Polarization Self-Rotation





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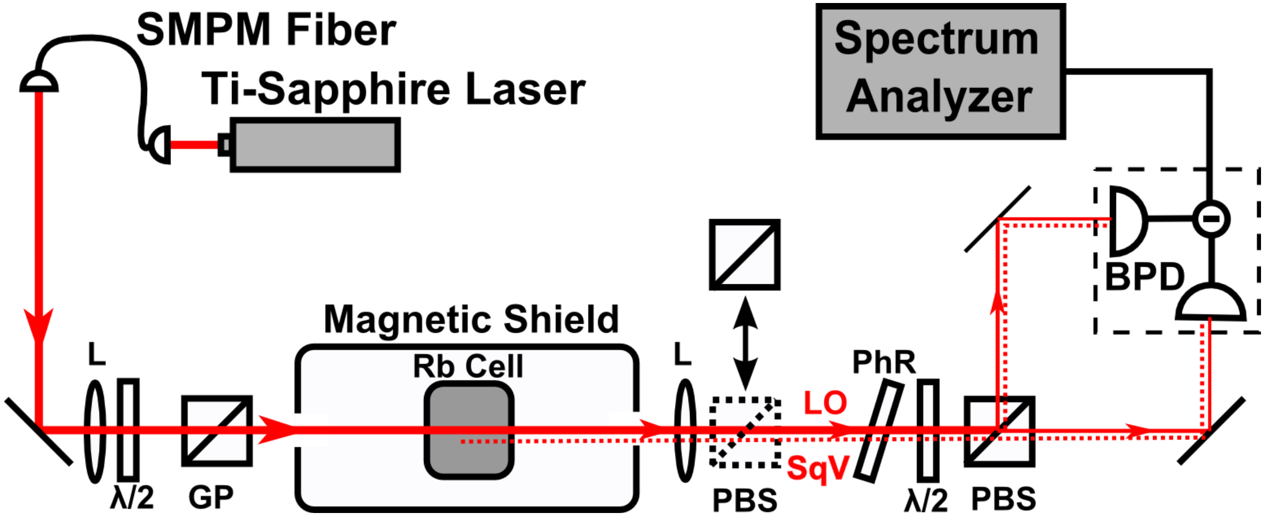
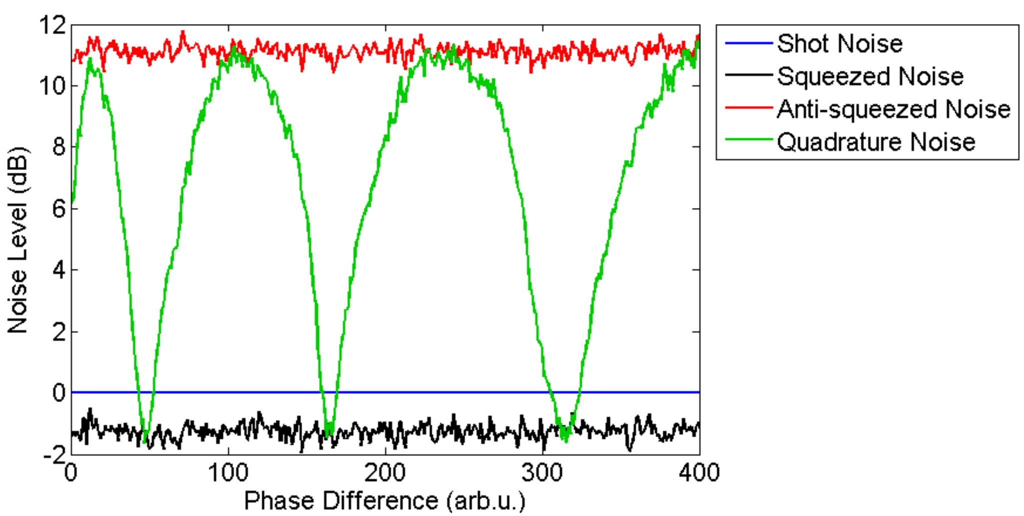
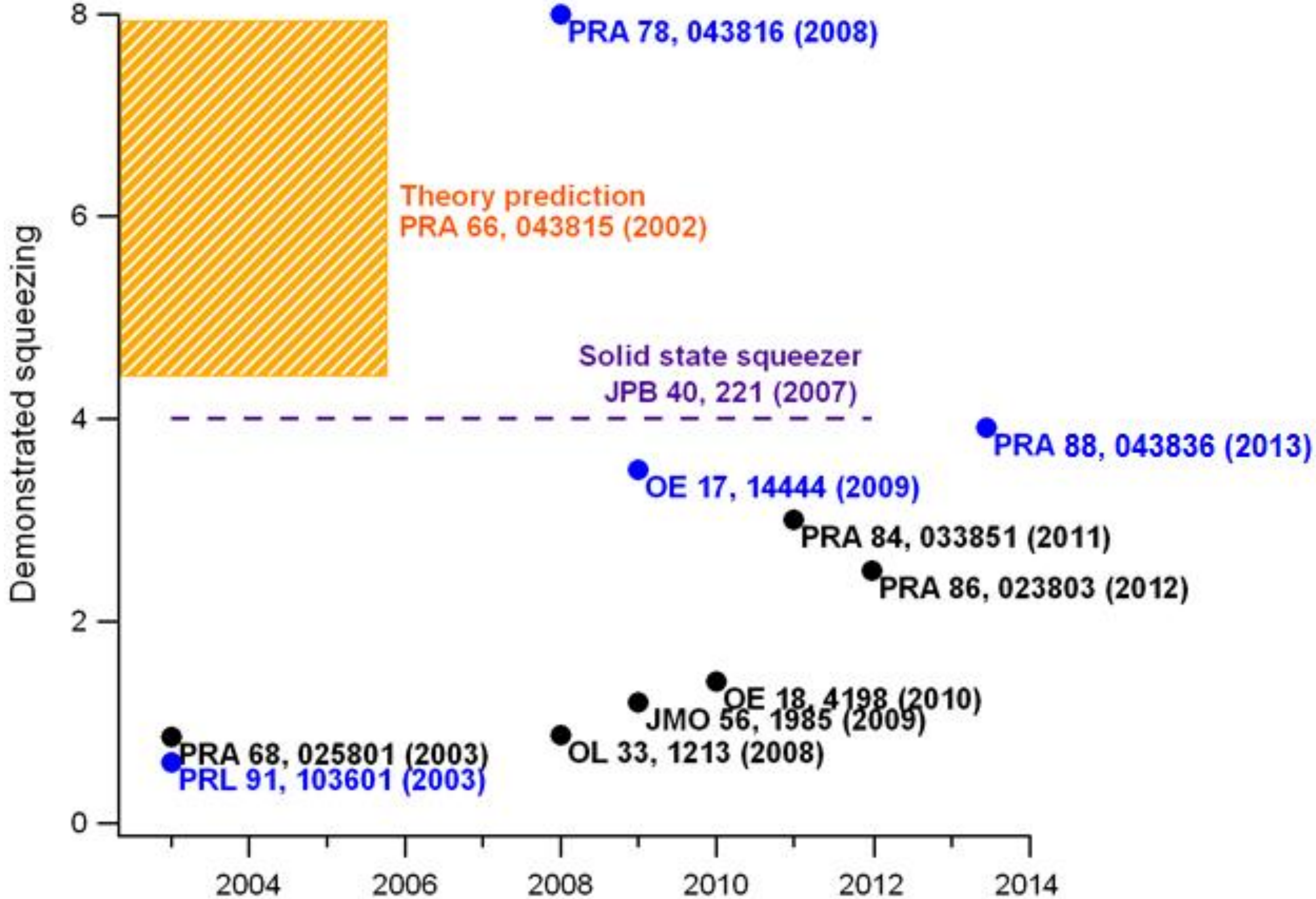
Setup



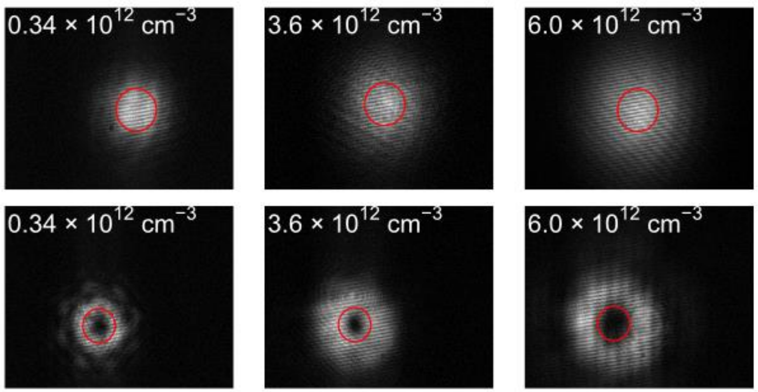
SMPM fiber - single-mode polarization-maintaining fiber
λ/2 - half-wave plate
GP - Glan-laser polarizer
PBS - polarizing beam splitter
PhR - phase-retarding wave plate
BPD - balanced photodetector

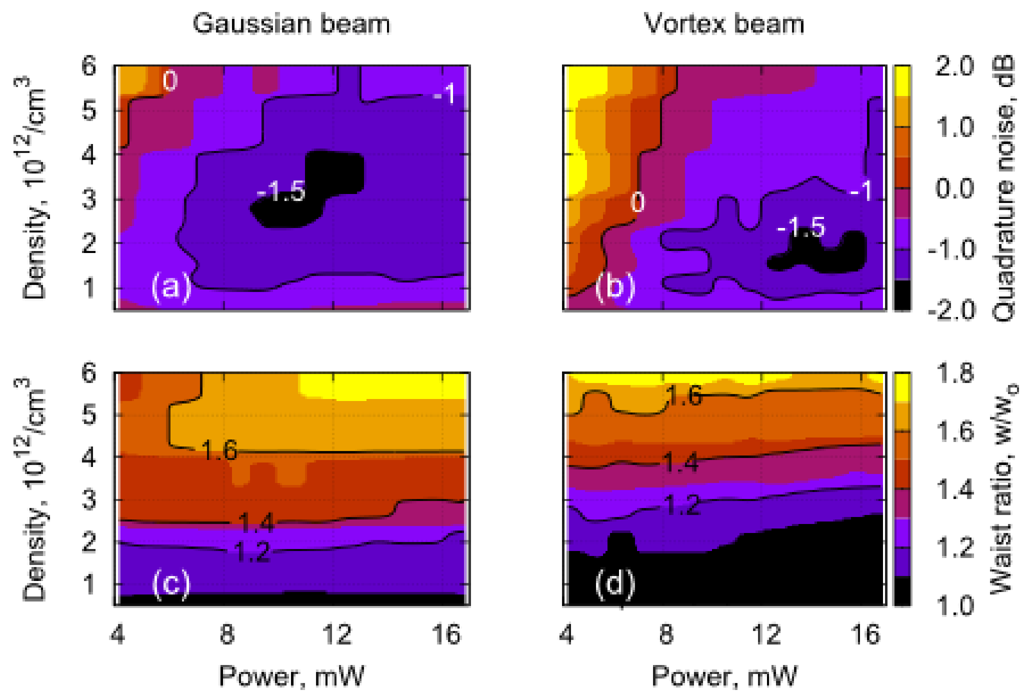


Development of Squeezing in atomic vapors



Self-(de)focusing

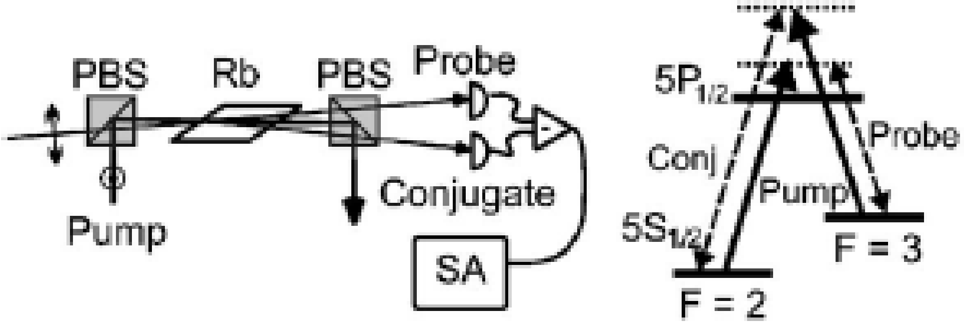


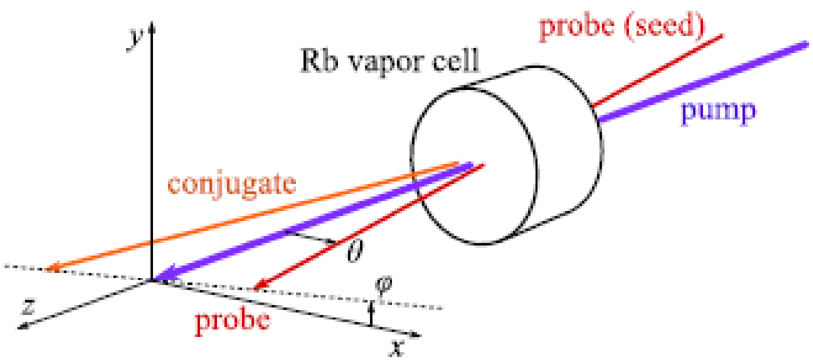


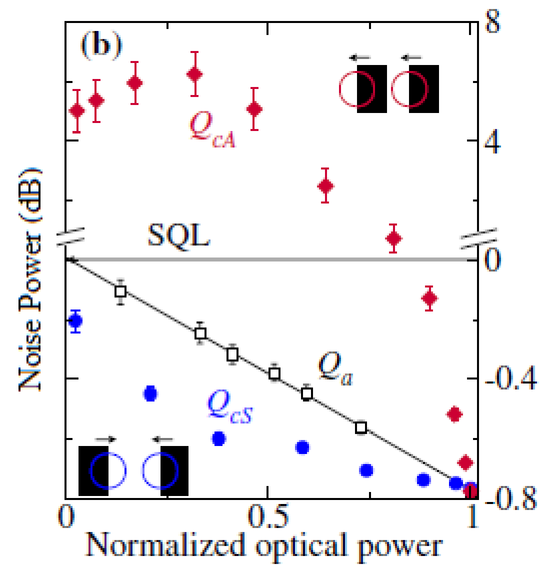
Expansion caused by Self-defocusing is irrelevant to squeezing amount.

Mi Zhang, Joseph Soultanis, Irina Novikova, and Eugeniy E. Mikhailov, Optics Letters, Vol. 38, Issue 22, pp. 4833-4836 (2013)

Spatial structure of beam after interaction

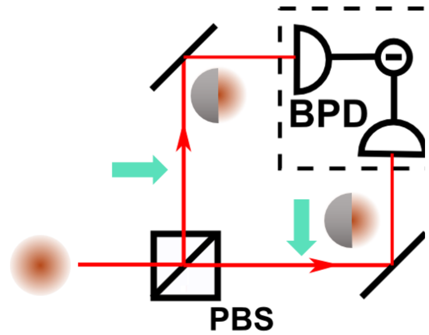


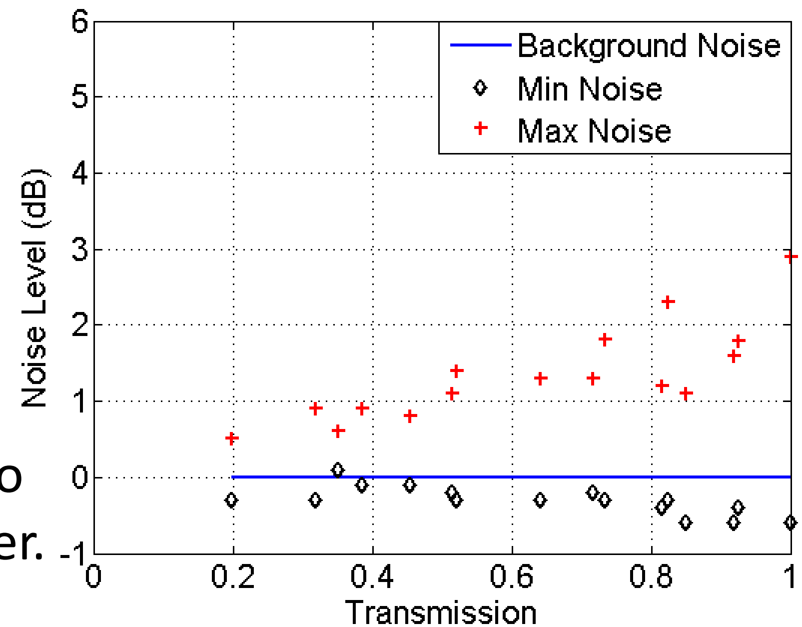




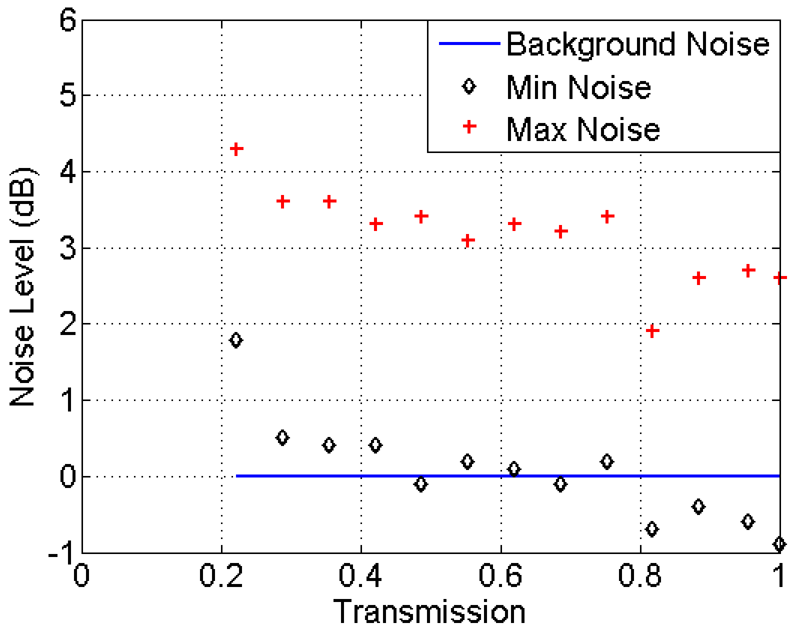
C. F. McCormick, V. Boyer, E. Arimondo, and P. D. Lett, Optics Letters, Vol. 32, Issue 2, pp. 178-180 (2007)
V. Boyer, A. M. Marino, and P. D. Lett, Phys. Rev. Lett. 100, 143601 (2008)

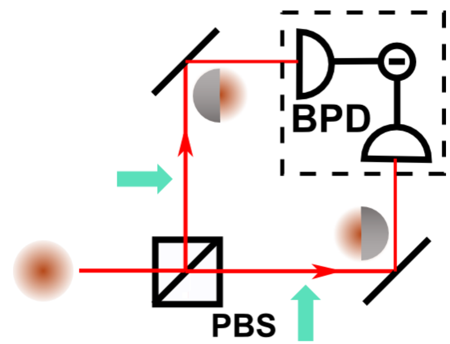
Spatial Mask – Sharp Edge





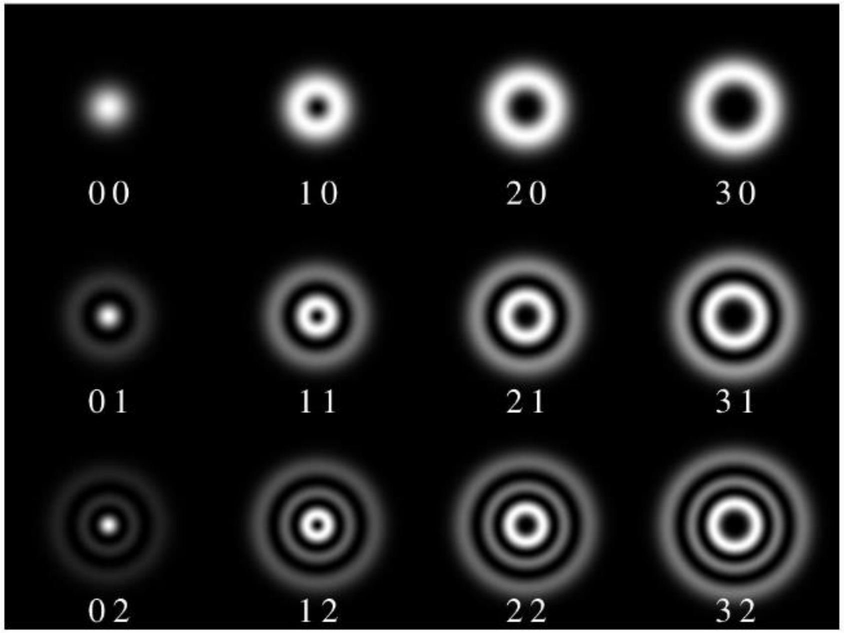
Blocking beams from the same sides is equivalent to modification before splitter.





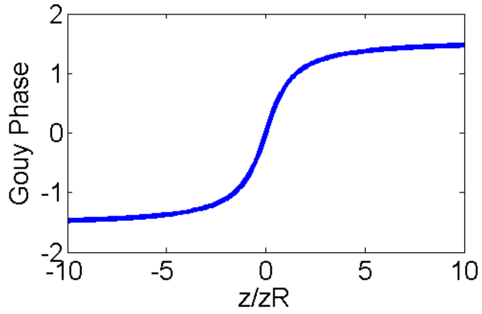
Beams blocked from opposite sides.

Laguerre Gaussian modes



Guoy Phase $\varsigma(z) = arctan\left(\frac{z}{z_R}\right)$,

has a π shift across the focus



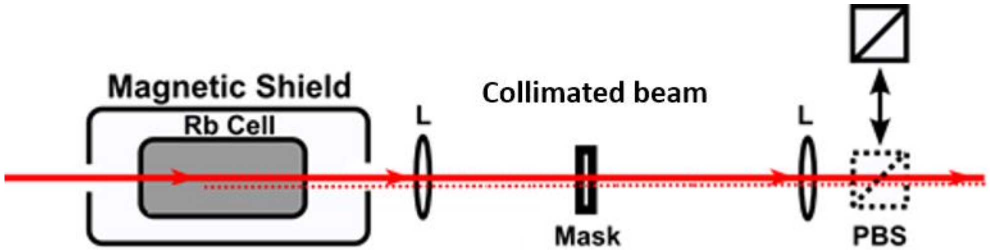
$$u_{pl}^{LG} = \frac{C_{pl}^{LG}}{w(z)}\left(\frac{r\sqrt{2}}{w(z)}\right)^{|l|} exp\left[-\frac{r^2}{w^2(z)}\right] L_p^{|l|} exp\left[-\frac{ikr^2 z}{2(z^2+z_R^2)}\right](-il\phi)exp\left[i(2p+|l|+1)tan^{-1}\frac{z}{z_R}\right]$$

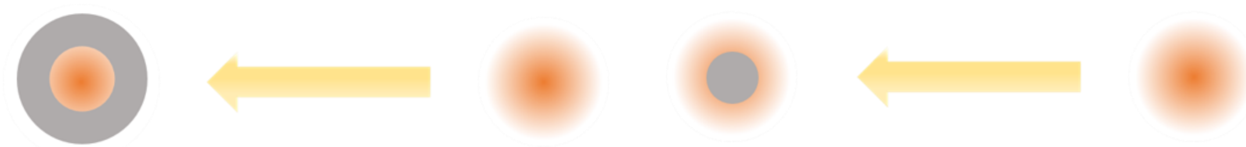
l : azimuthal index

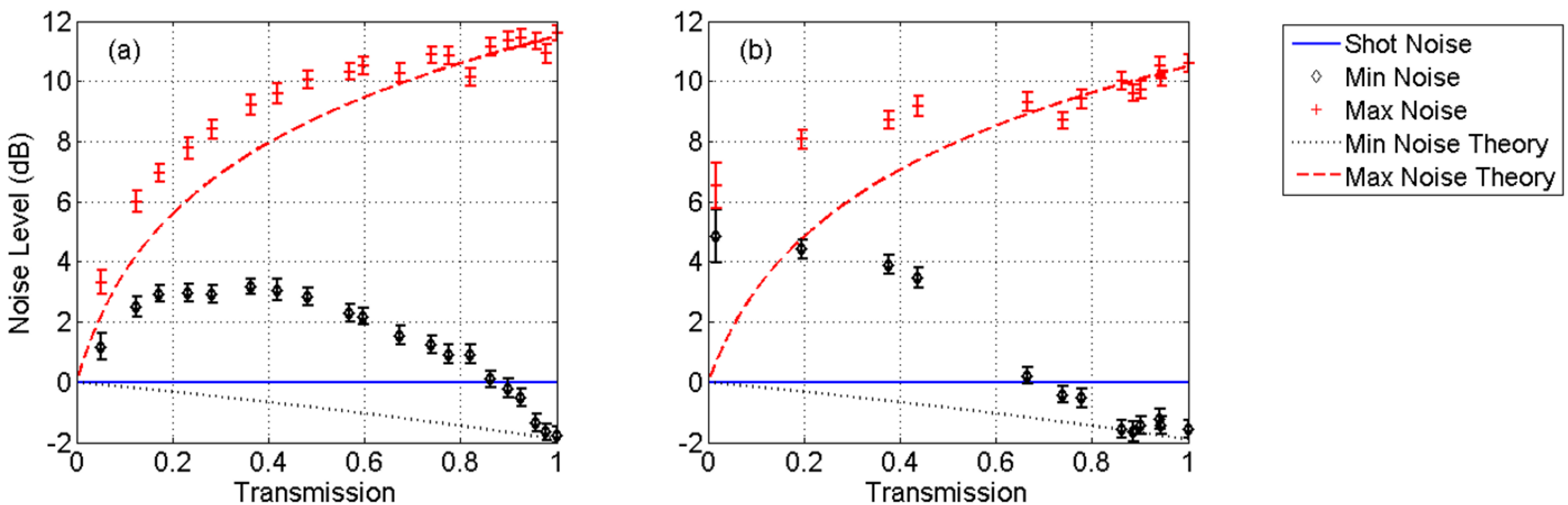
p : radial index

L Allen, M.J Padgett, Optics Communications, Volume 184, Issues 1–4, 1 October 2000

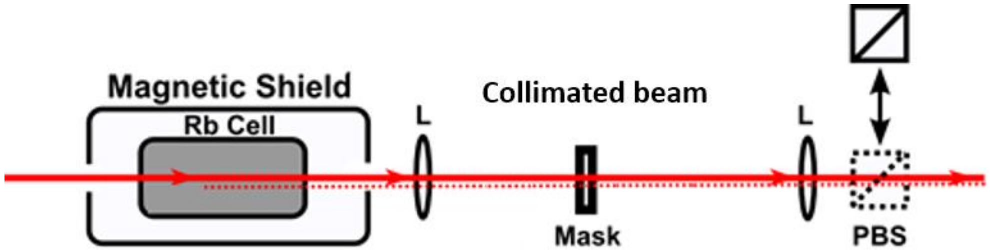
Spatial Mask – Ring Mask

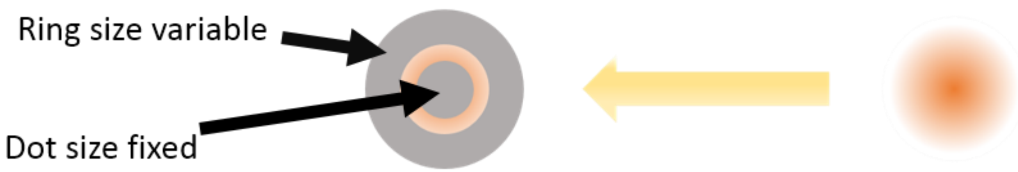


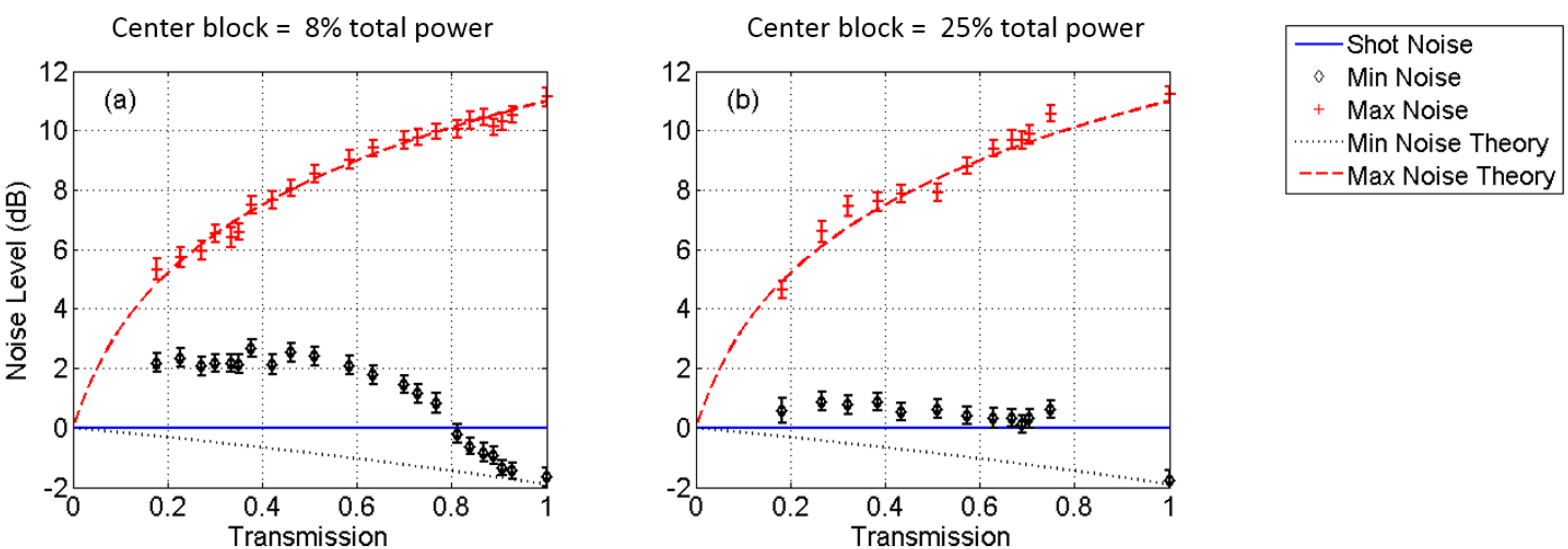




Spatial Mask – Circular Mask







Possible composition of beam

Instead of sending in higher LG modes, we might be generating them.

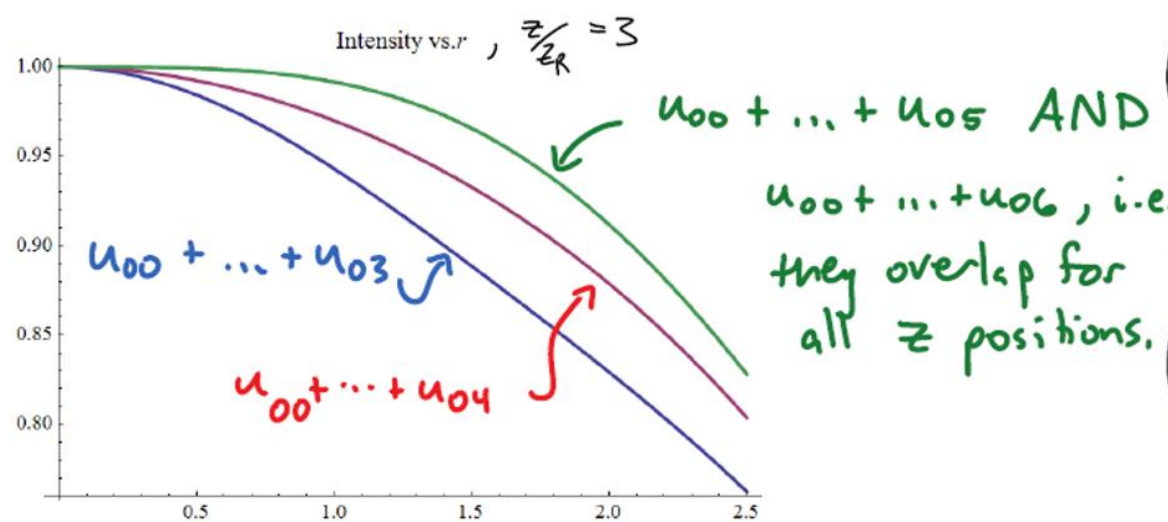
Propagation function: $\hat{L}\Omega_x = -i\left(\frac{\kappa}{\Delta}\right)(u^*u)^2\Omega_x$

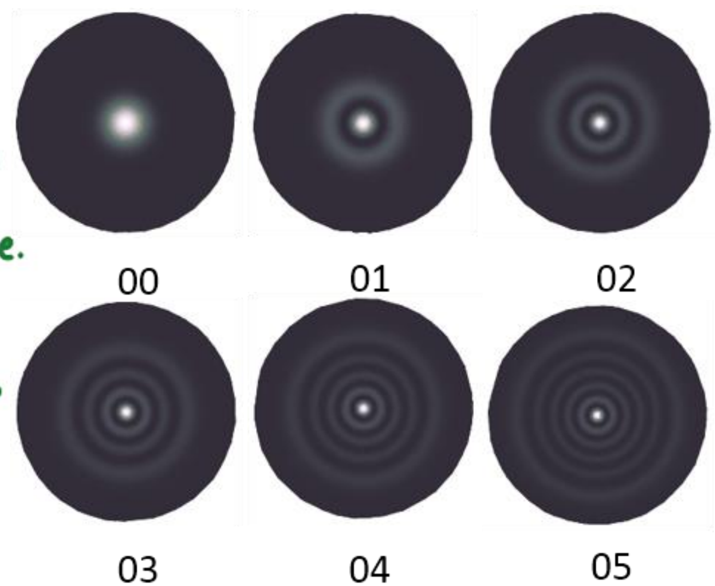
Solution: $\Omega_x = \Omega_{x0} + \sum_p u_{0p}\int dz' c_p(z'), \quad c_p(z') = \int r' dr' u_{0p}^*(r', z')\rho_x(r', z')$

Q : How Many Modes Should We Add?

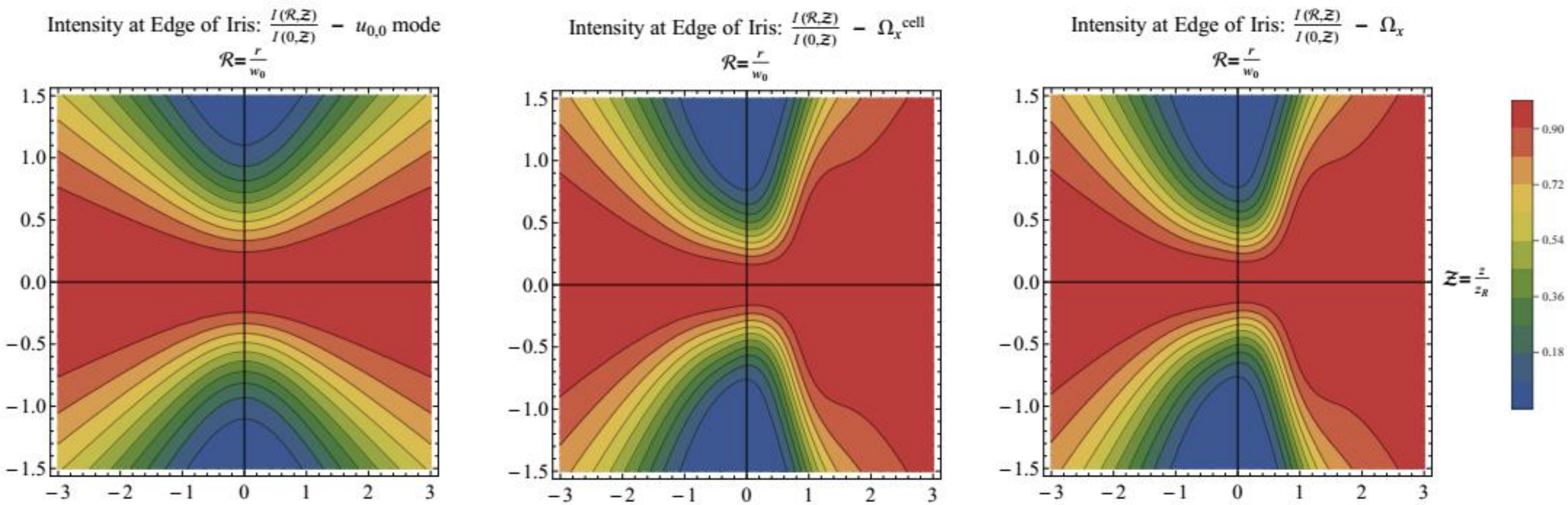
A : 5.

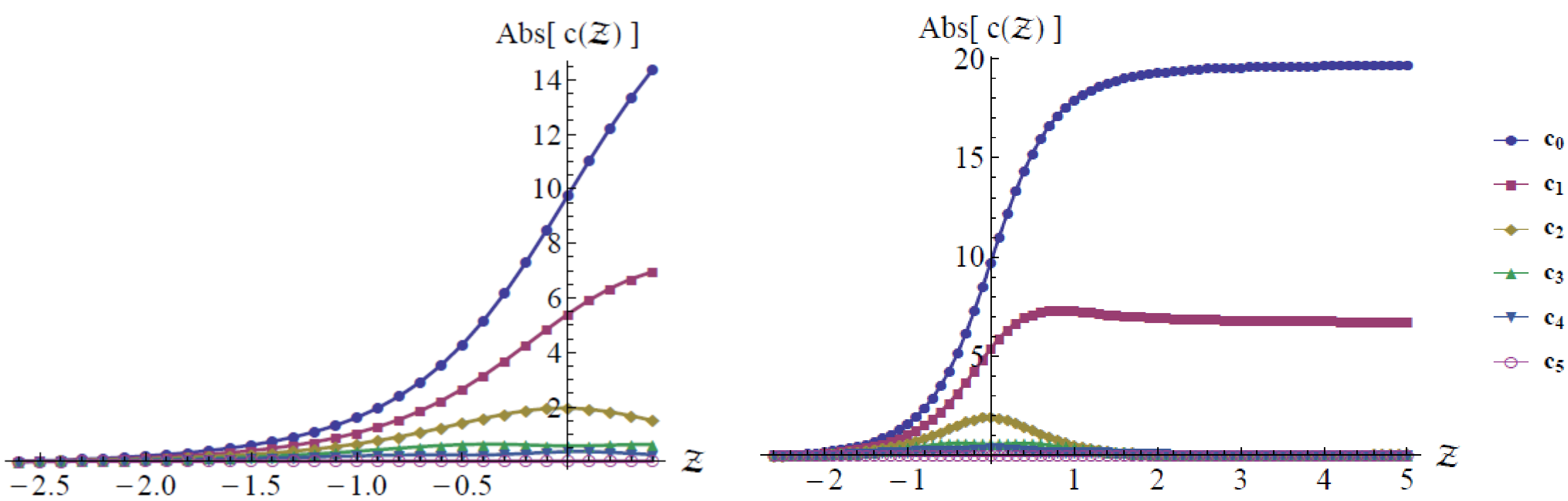
An analysis reveals we must keep up to p=5 in our superposition.





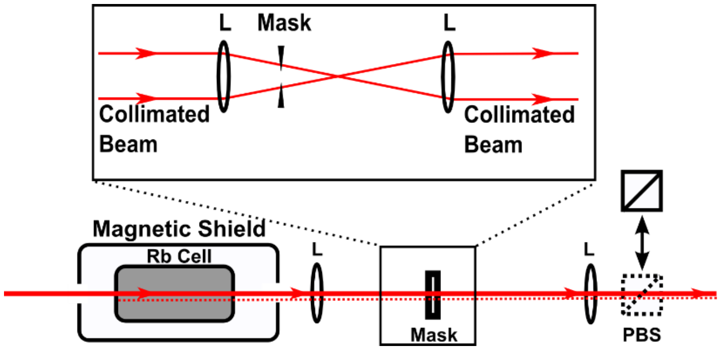
Evolution of multimode beam

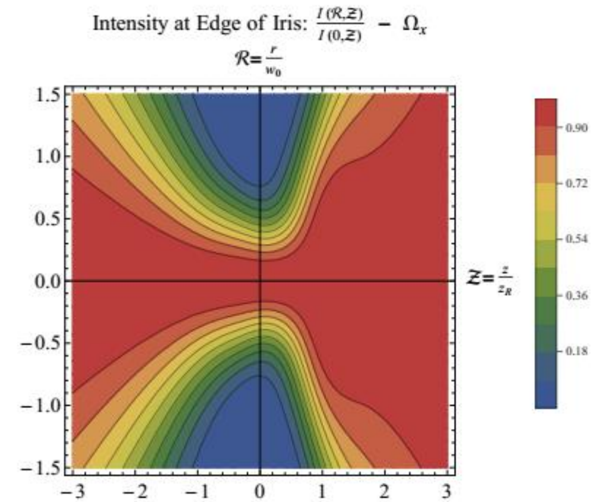


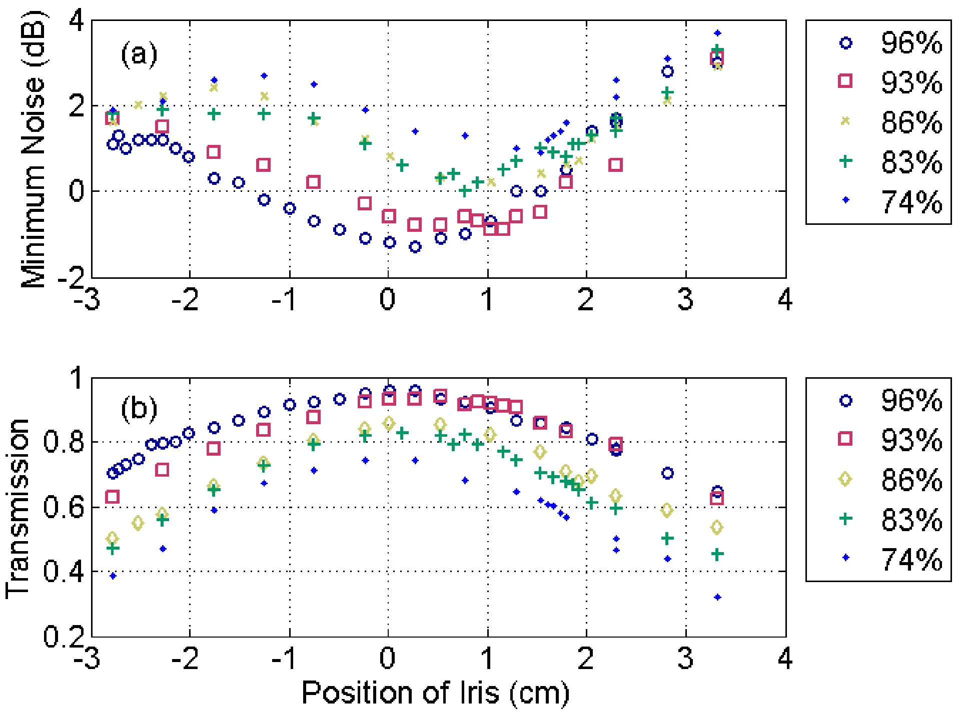


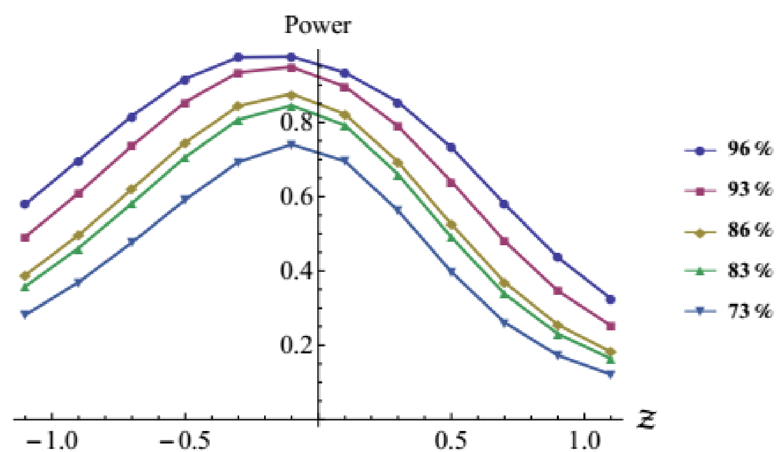
Longer cell?

Fixed Iris Size

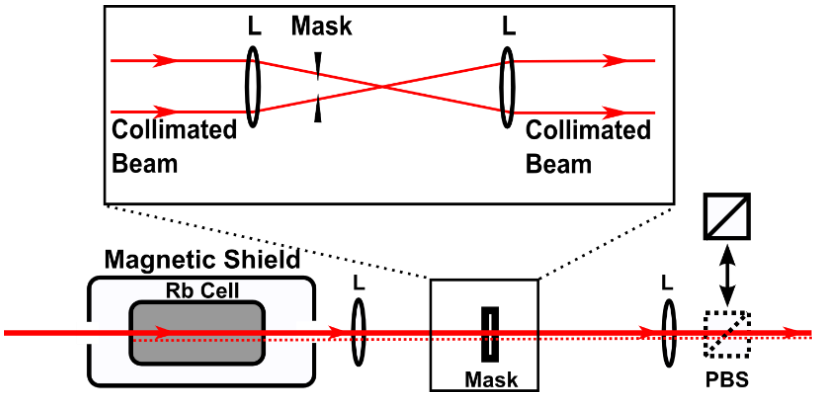


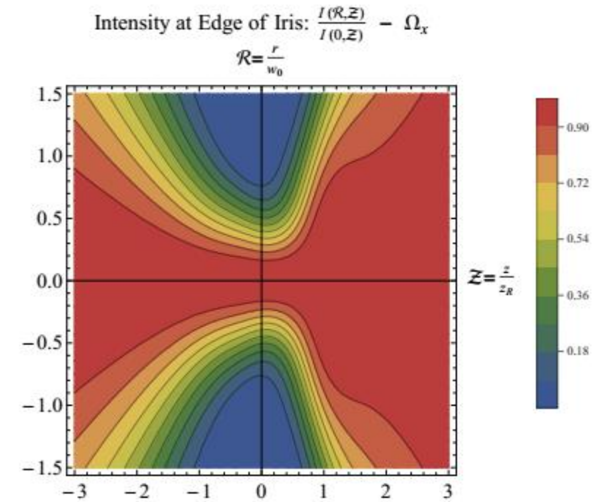


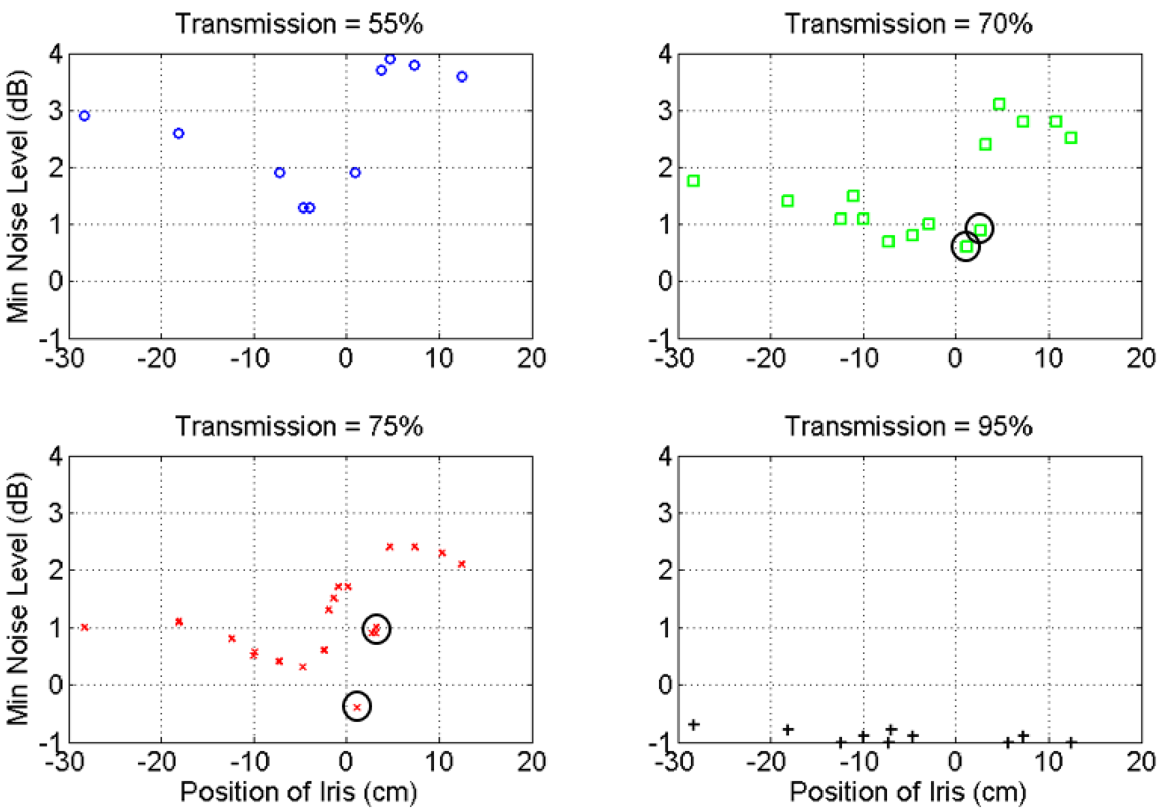




Fixed Transmission







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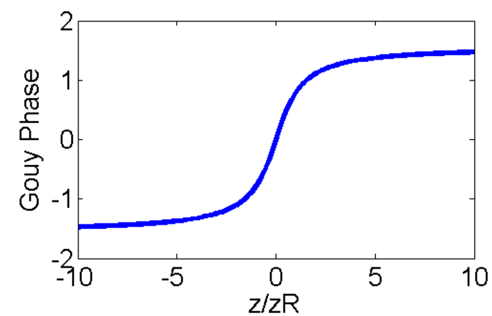

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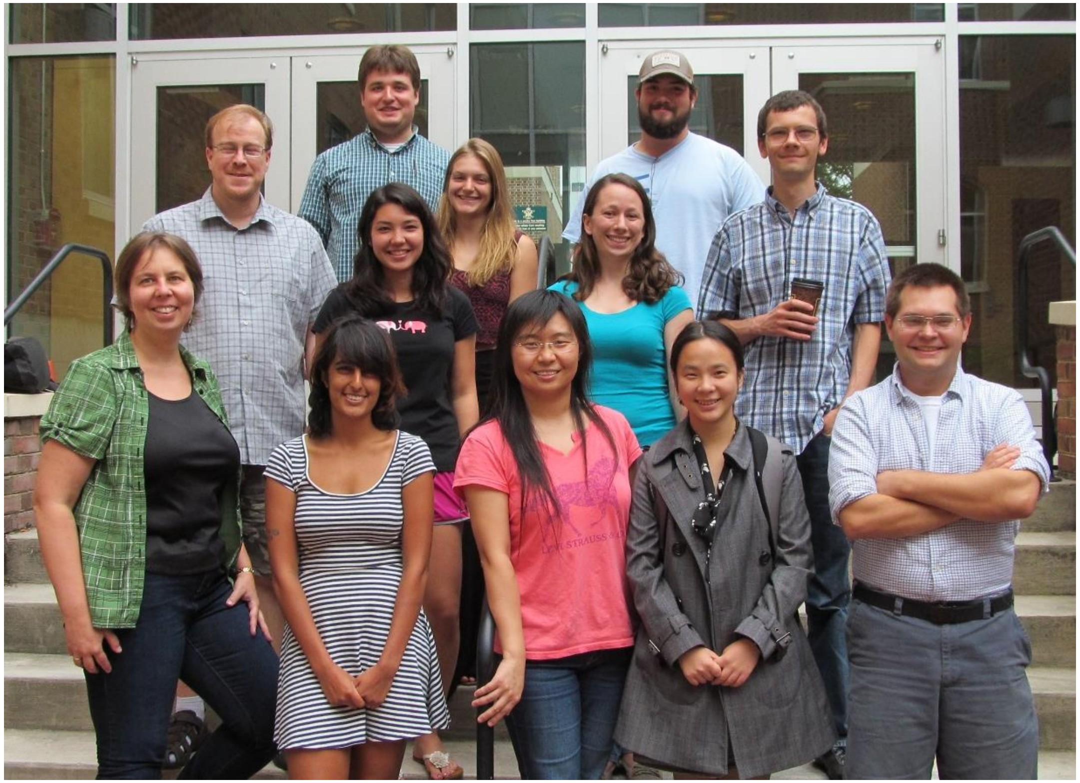

Conclusion

- We generated a squeezed vacuum state from polarization self-rotation.
- The squeezed vacuum state consists of high order Laguerre Gaussian modes with different squeezing parameters.