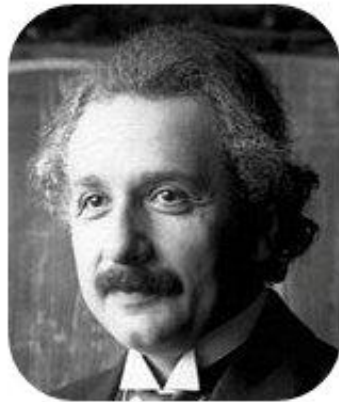# Bessel-Gaussian entanglement

M. McLAREN[1,2], F.S. ROUX[1] & A. FORBES[1,2,3]

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our future through science

Entanglement: "spooky action at a distance"

A. Einstein   B. Podolsky   N. Rosen
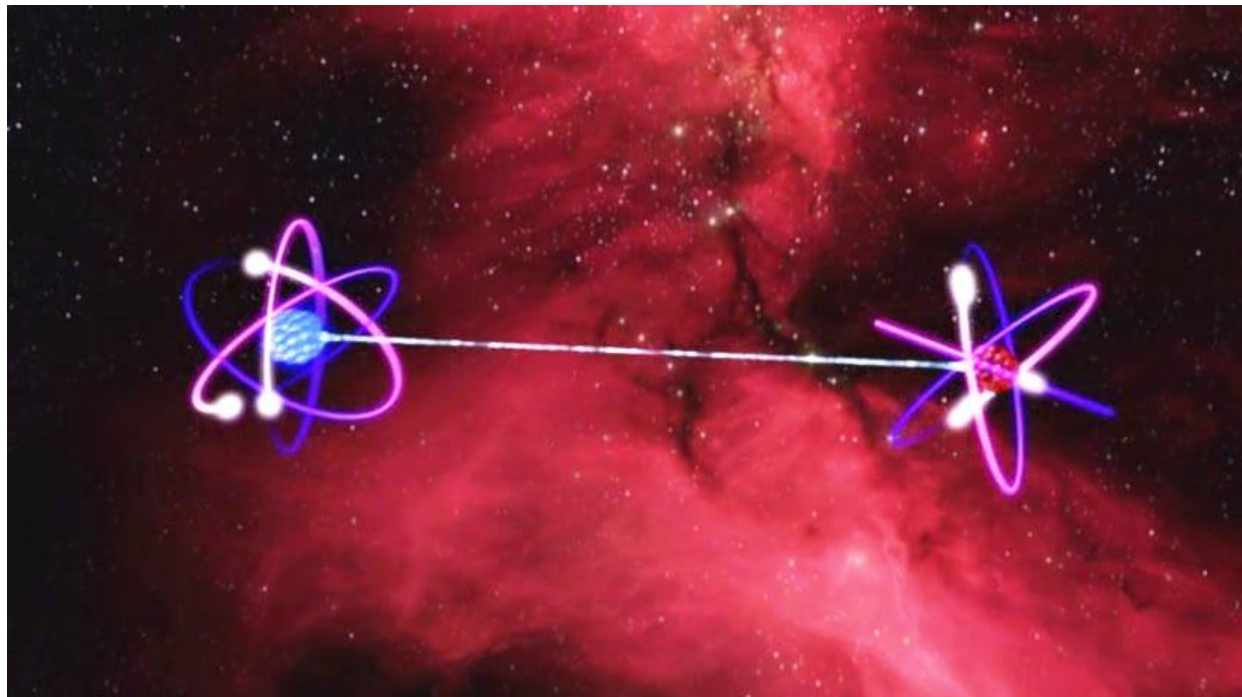
Engineering quantum states for specific applications

$$|\psi\rangle = a \; \boxed{} \; + \; b \; \boxed{} \; + \; c \; \boxed{} \; + \; \cdots$$

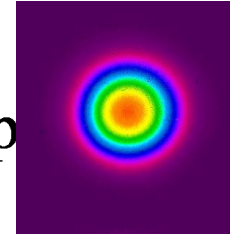OAM spectrum

0.7   0.3   0.3
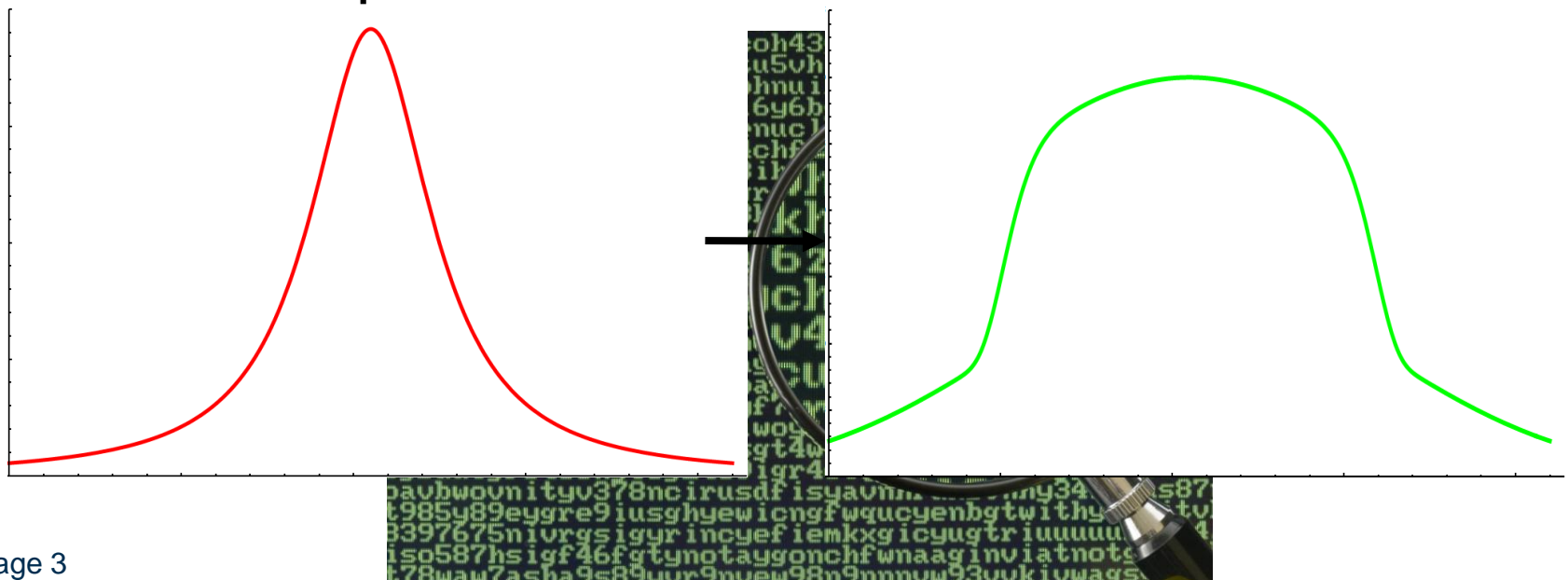
Azimuthally-phased beams have helical wavefronts and consequently carry OAM.

Spin Clockwise: 1   **Spin Anticlockwise: 0**

$$u(r,\theta,z) = u_0(r,z)\exp\left(\ell = 0\right)$$

$$|\psi\rangle = \sum_{\ell=-\infty}^{\infty} a_{\ell,-\ell}|\ell,-\ell\rangle$$

GAUSSIAN BEAM   15

LAGUERRE-GAUSSIAN BEAM   3

4
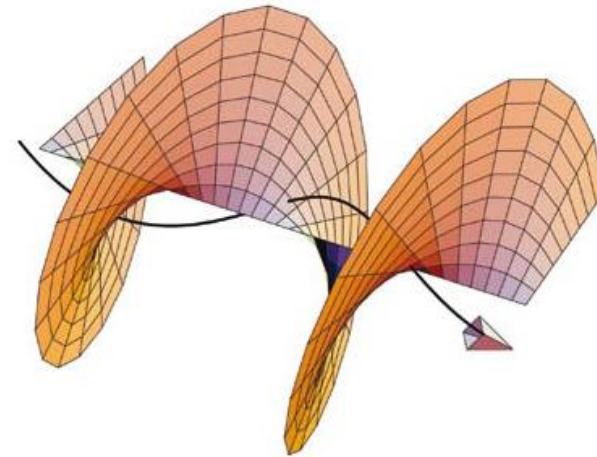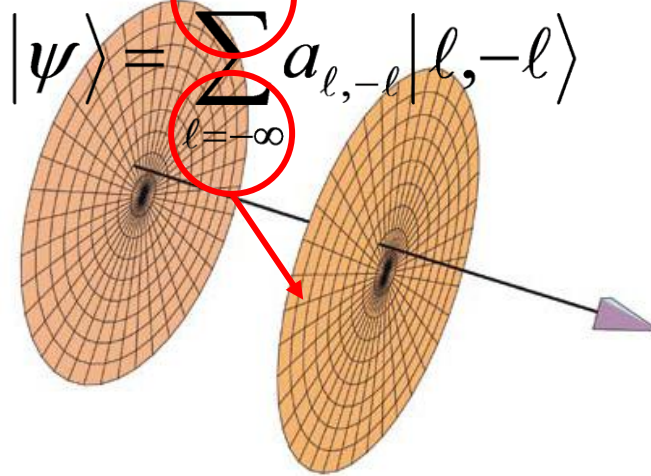
coin. counts $[s^{-1}]$
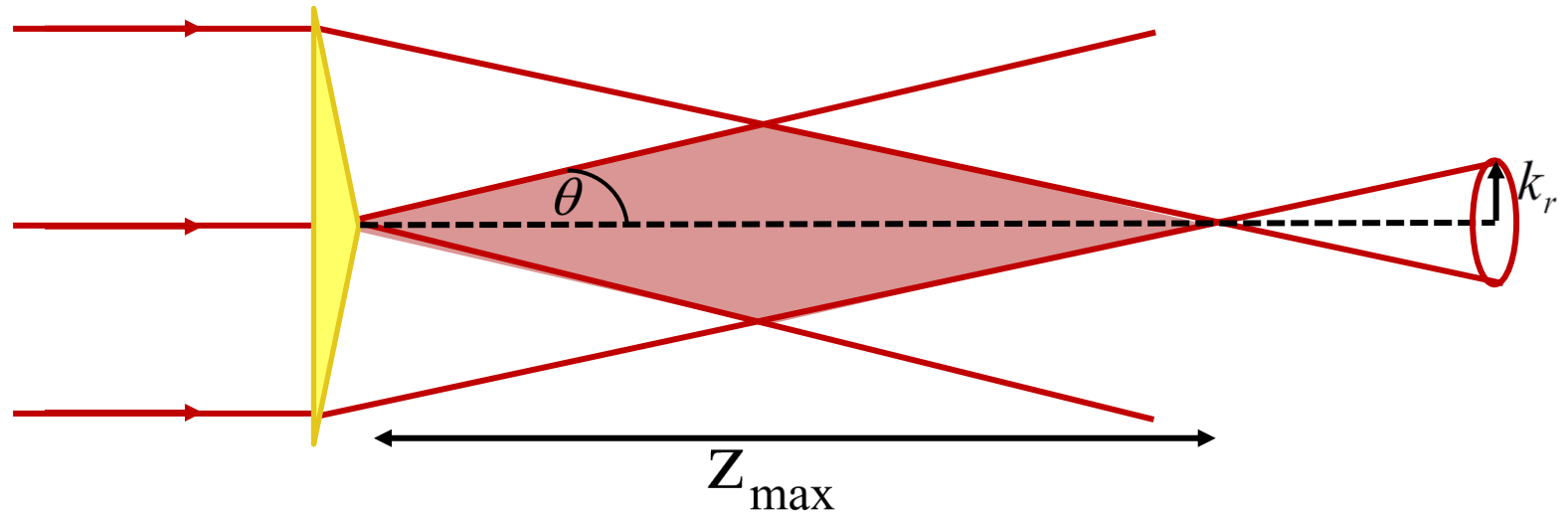
600

400

200

0

−20   10   20
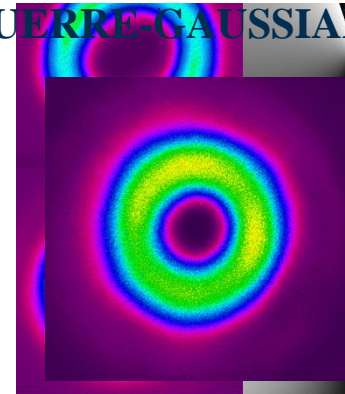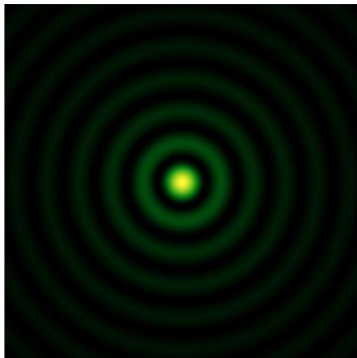
A
B
C
D
E

Higher-order Bessel-Gaussian beams carry OAM

$$u(r, \theta, z) = J_\ell(k_r r) \exp(i\ell\theta)$$
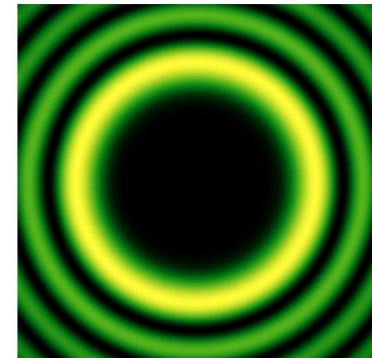

θ
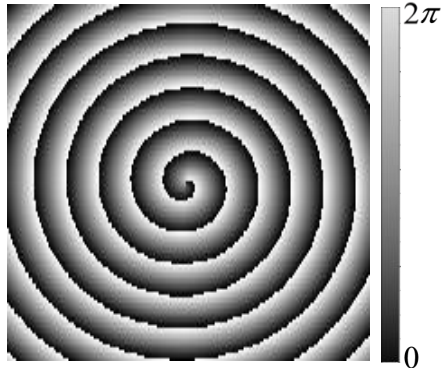
Z_{max}

k_r
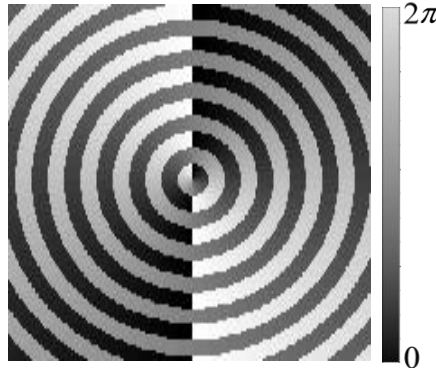
$\ell = 0$

$\ell = 1$
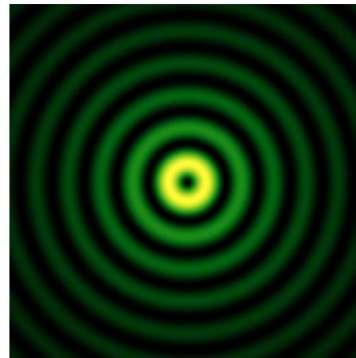
$\ell = 10$

Generating Bessel-Gaussian beams using spatial light modulators (SLMs)

$\exp(ik_r r)\exp(i\ell\phi)$

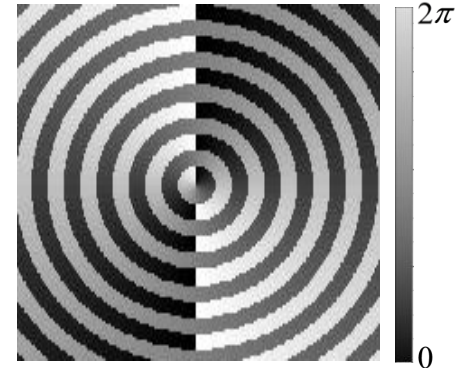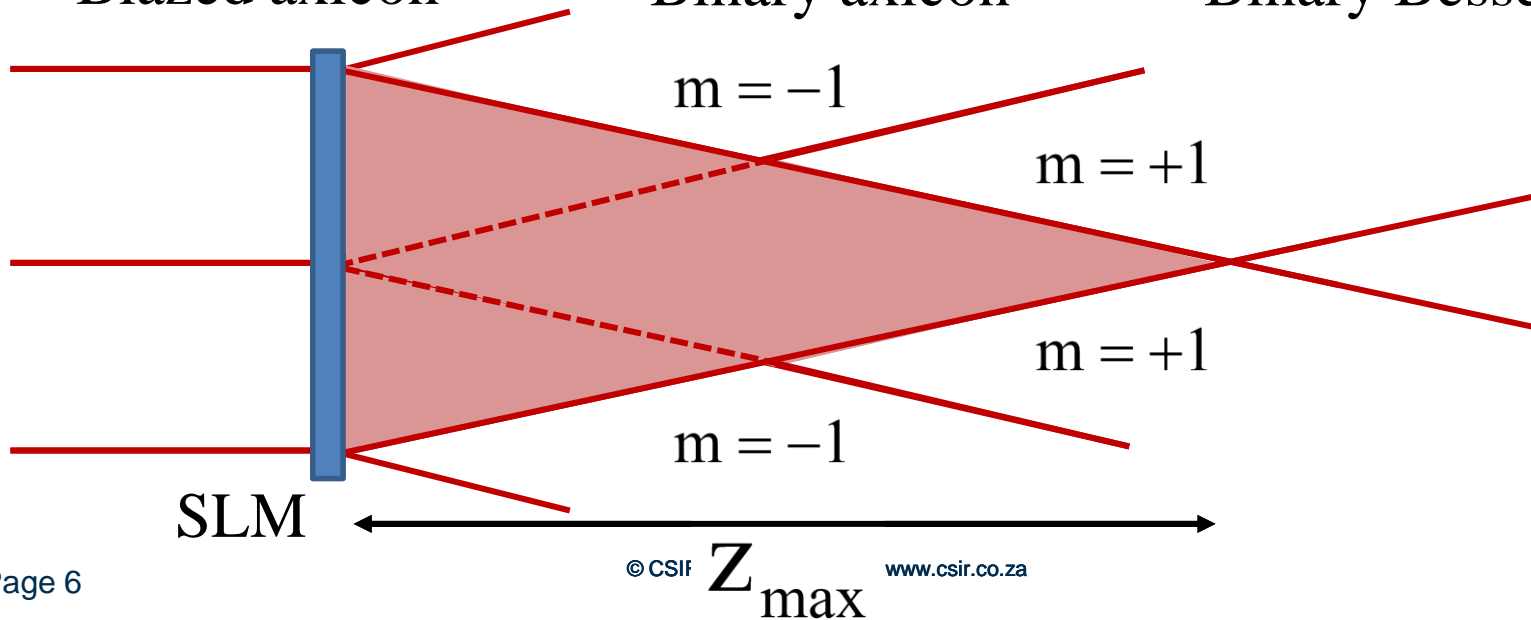Blazed axicon

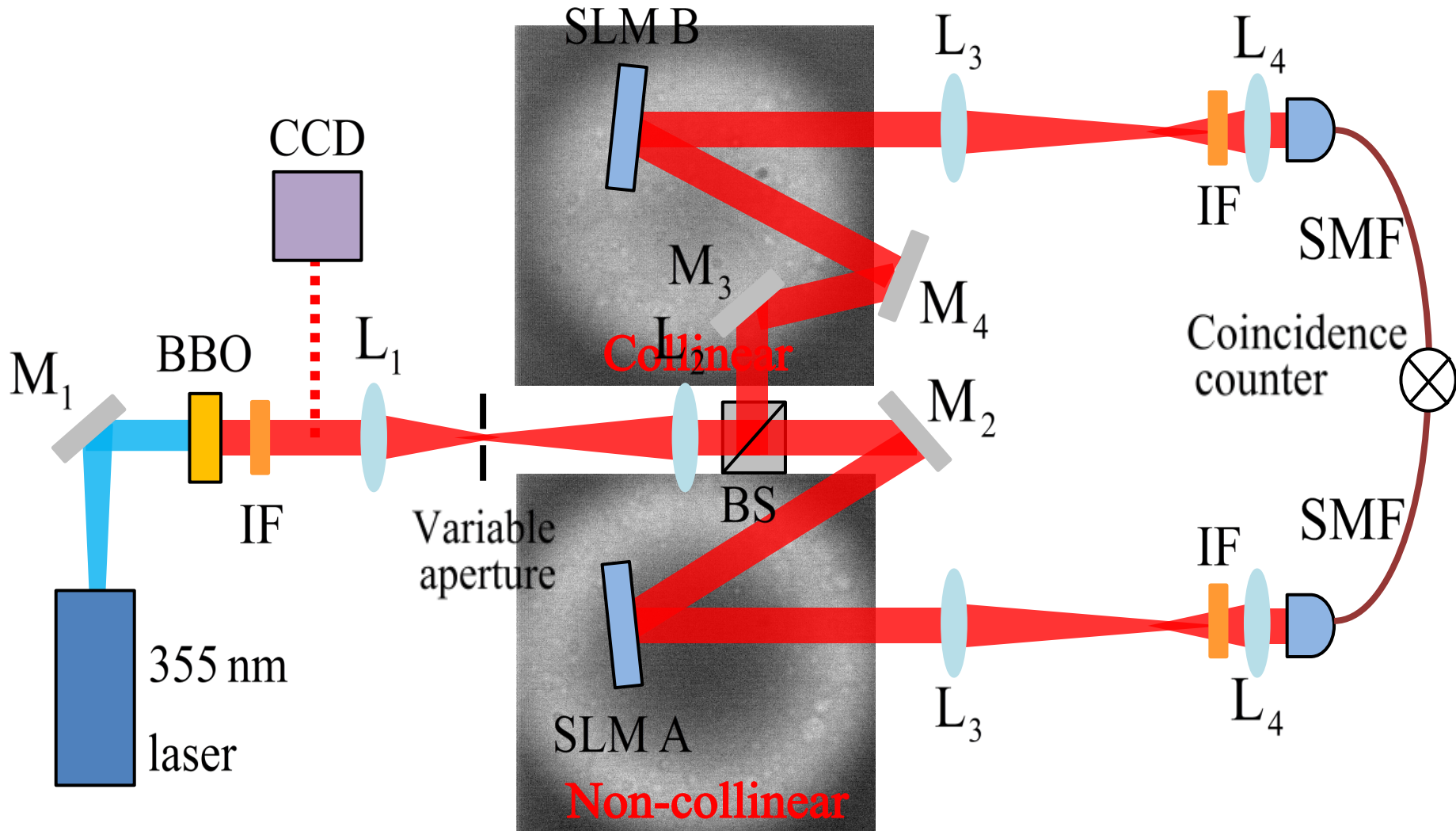$\mathrm{sign}\{\exp(ik_r r)\}\exp(i\ell\phi)$

Binary axicon

$\mathrm{sign}\{J_\ell(k_r r)\}\exp(i\ell\phi)$

Binary Bessel

$m = -1$
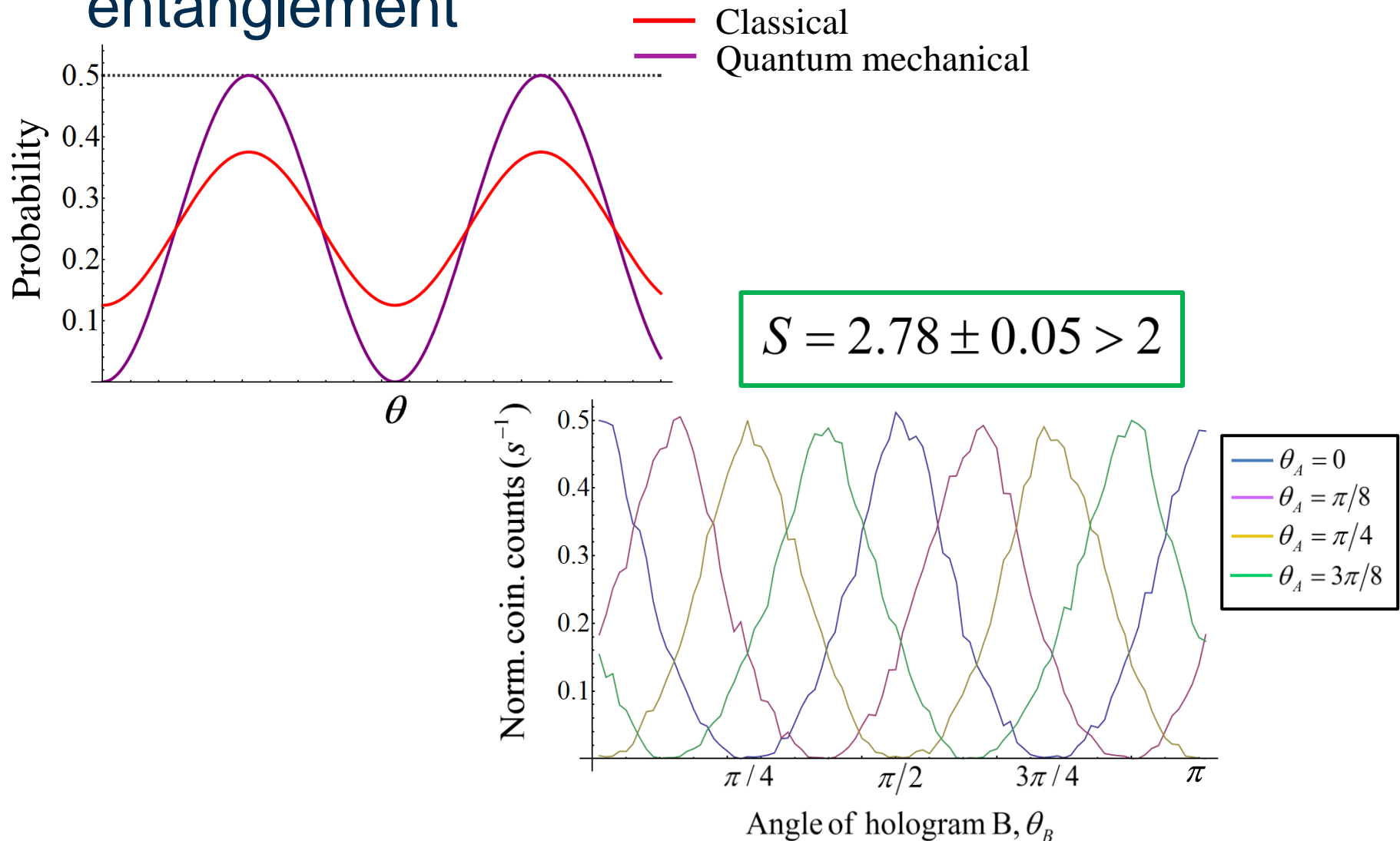
$m = +1$

$m = +1$

$m = -1$

SLM

Z_{max}

Experimental setup to detect entanglement

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Experimental setup to detect entanglement

BG mode

Hologram

Gaussian mode

$\ell = 2$

$\ell = 2$

$\ell = 0$

Single-mode fibre

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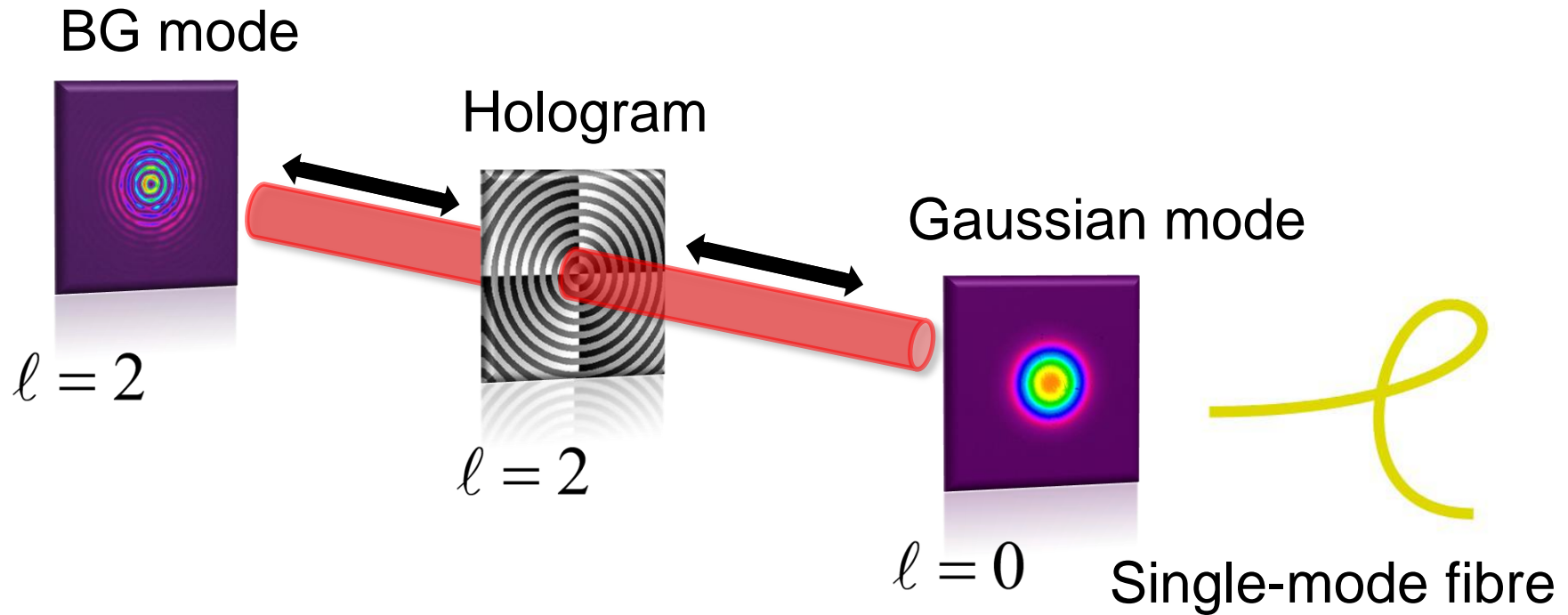
Violation of Bell's inequality demonstrates entanglement

— Classical
— Quantum mechanical

$$S = 2.78 \pm 0.05 > 2$$

M. McLaren et al., 2012, *Opt. Express*, **20**, 23589

Comparison of OAM spectra – measuring coincidence count rates

OAM is conserved

M. McLaren et al.,2013, arXiv:1306.2767v1 [quant-ph]
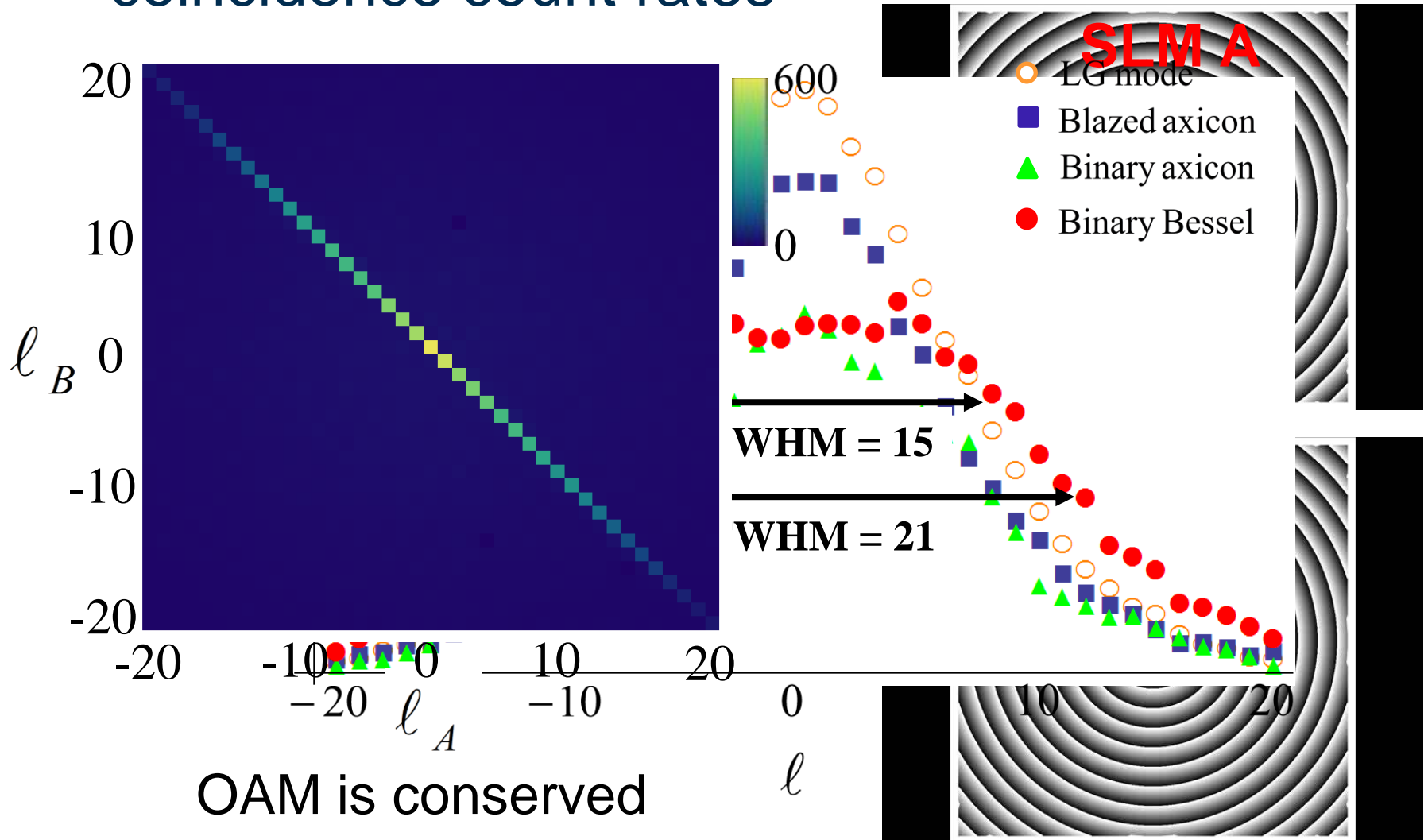
OAM spectrum is dependent on the radial component

Legend:
- $k_r = 0$ rad/mm
- $k_r = 20$ rad/mm
- $k_r = 35$ rad/mm

M. McLaren et al.,2013, arXiv:1306.2767v1 [quant-ph]
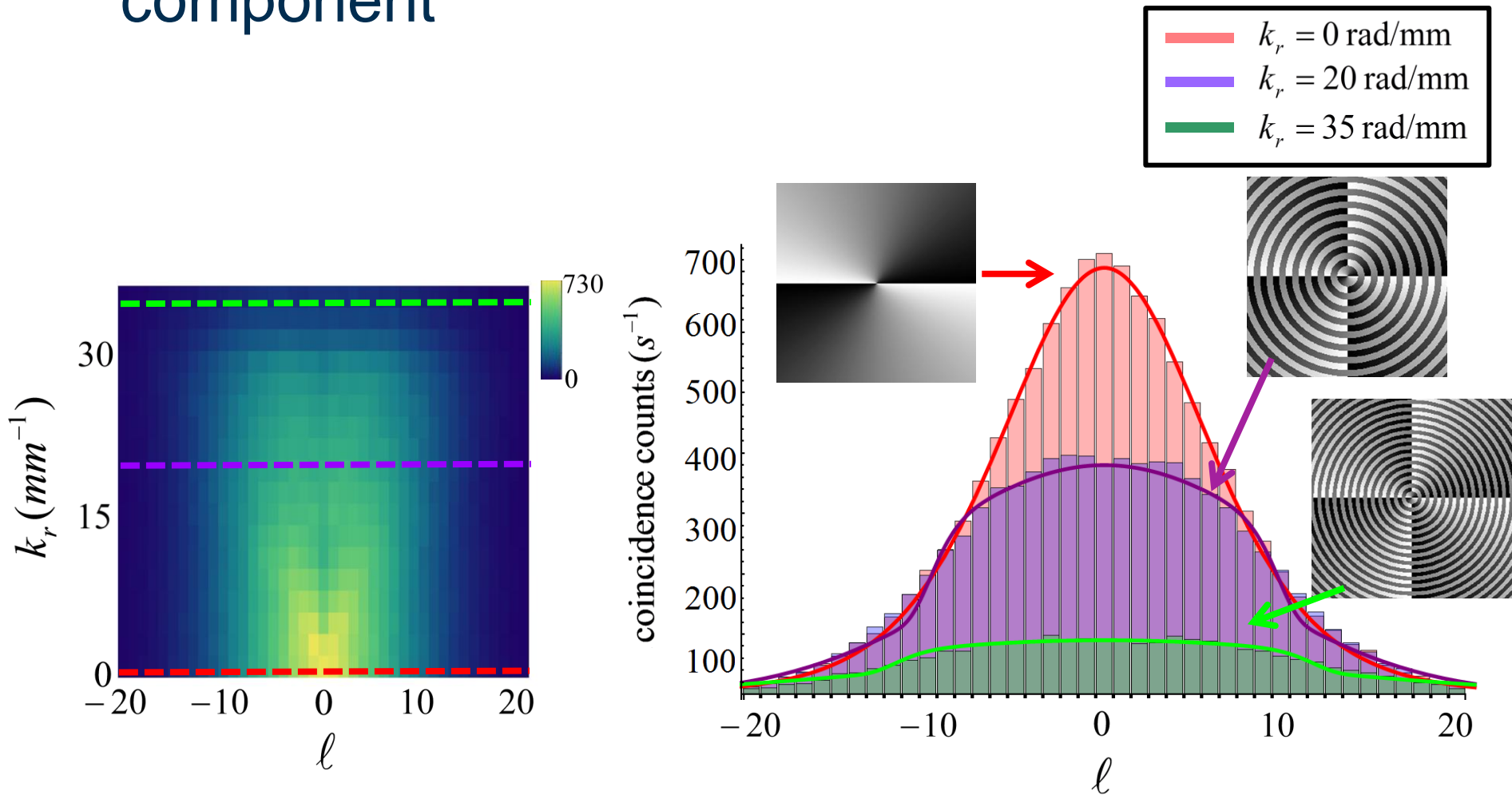
Reconstruction of the density matrix using a full state tomography
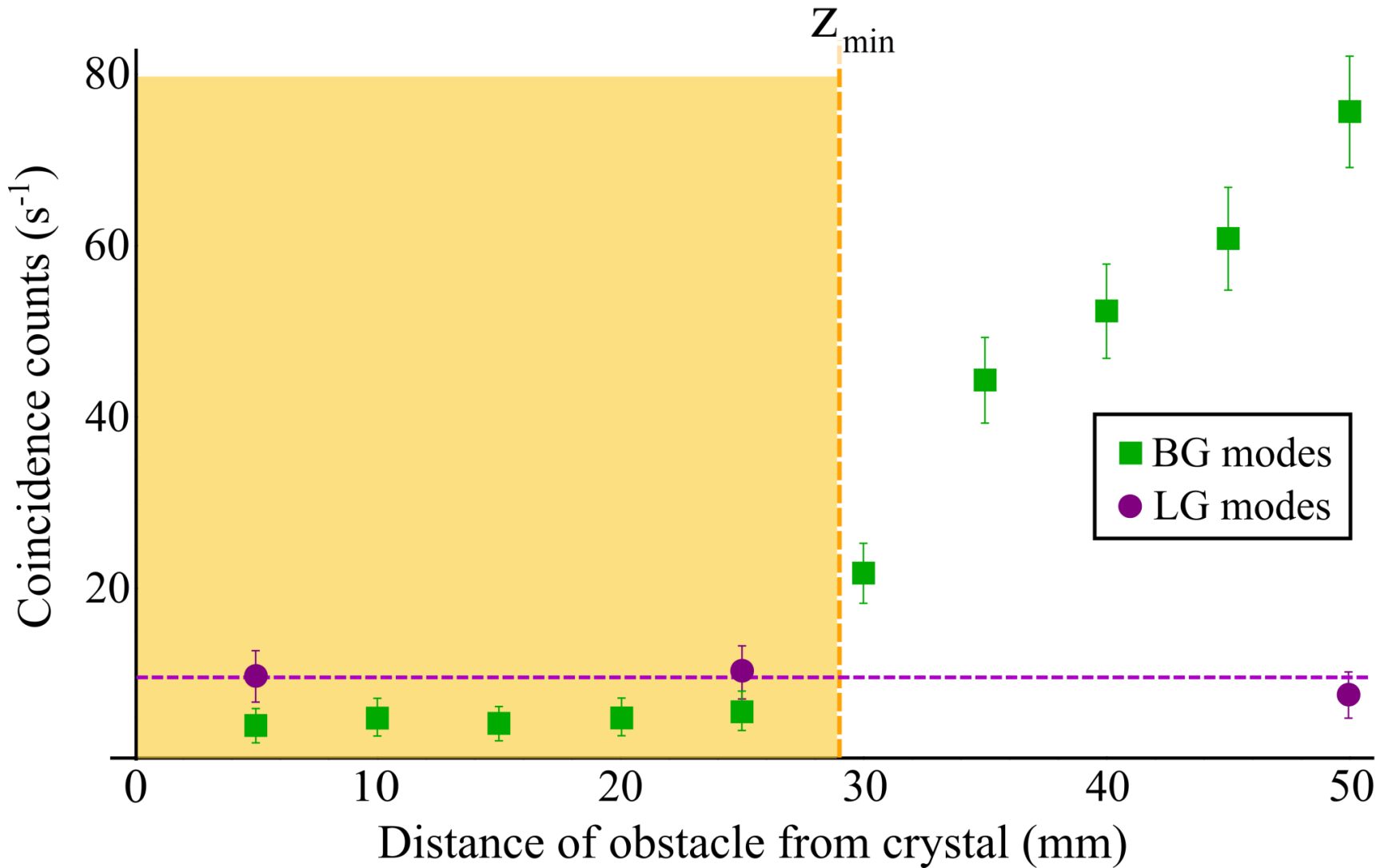

M. McLaren et al.,2012, *Opt. Express*, **20**, 23589
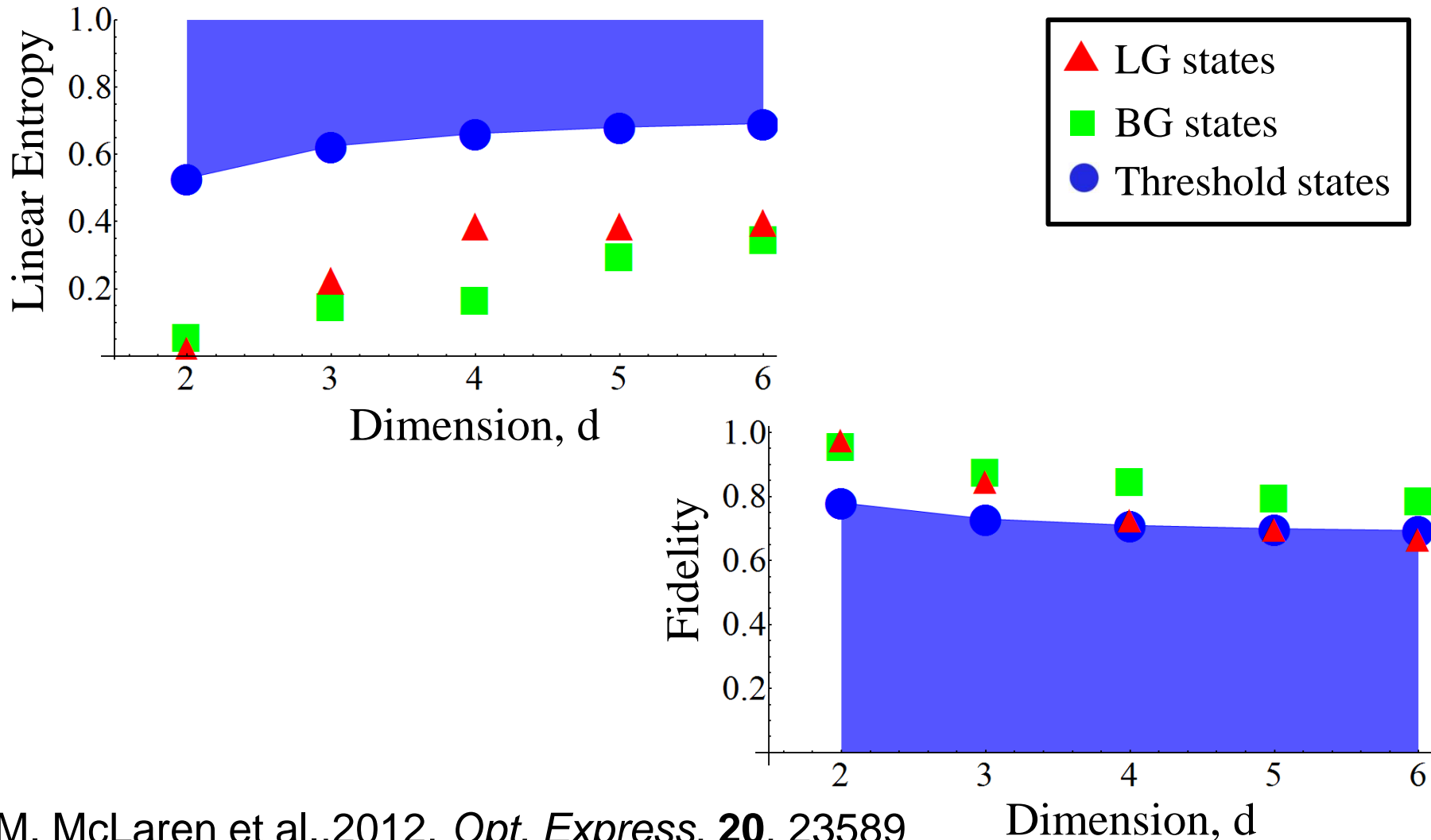
Properties of Bessel-Gauss beams – reconstruction after an obstruction
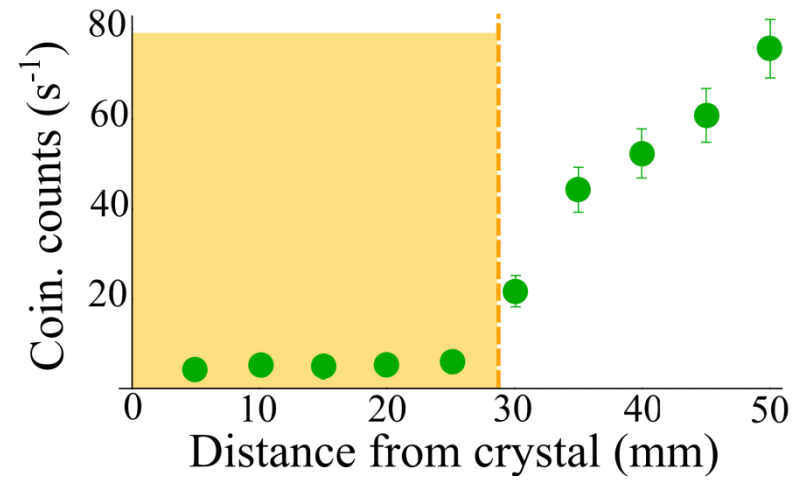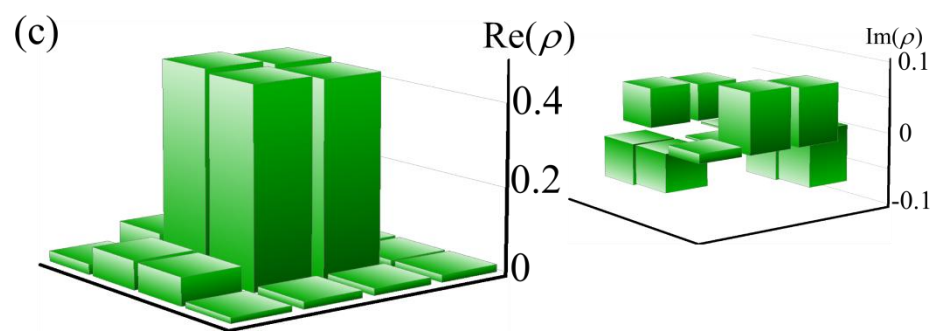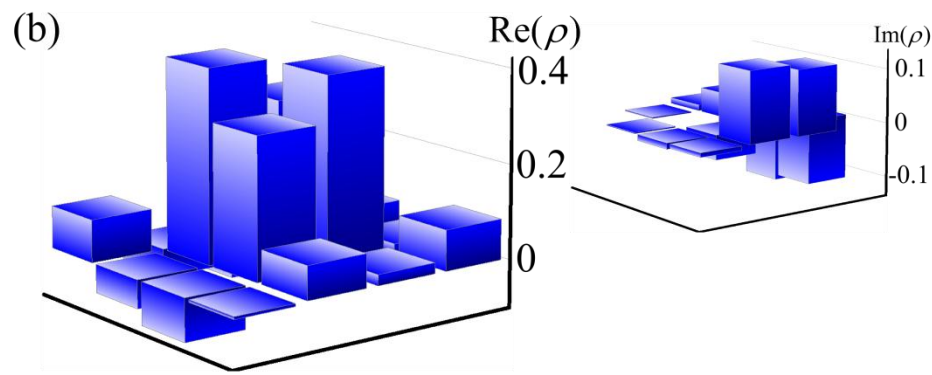

$$Z_{min}$$

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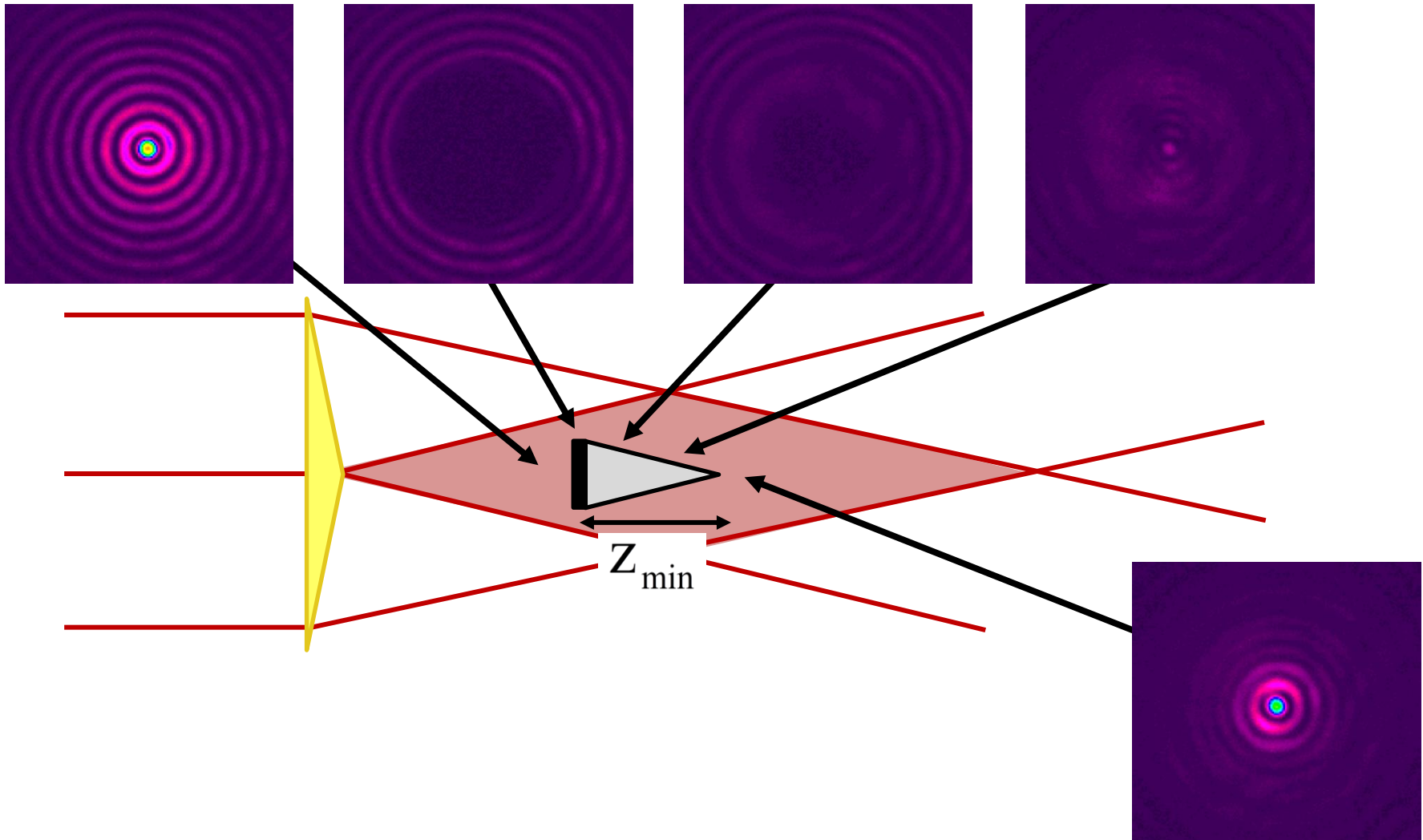
Entanglement setup with obstruction

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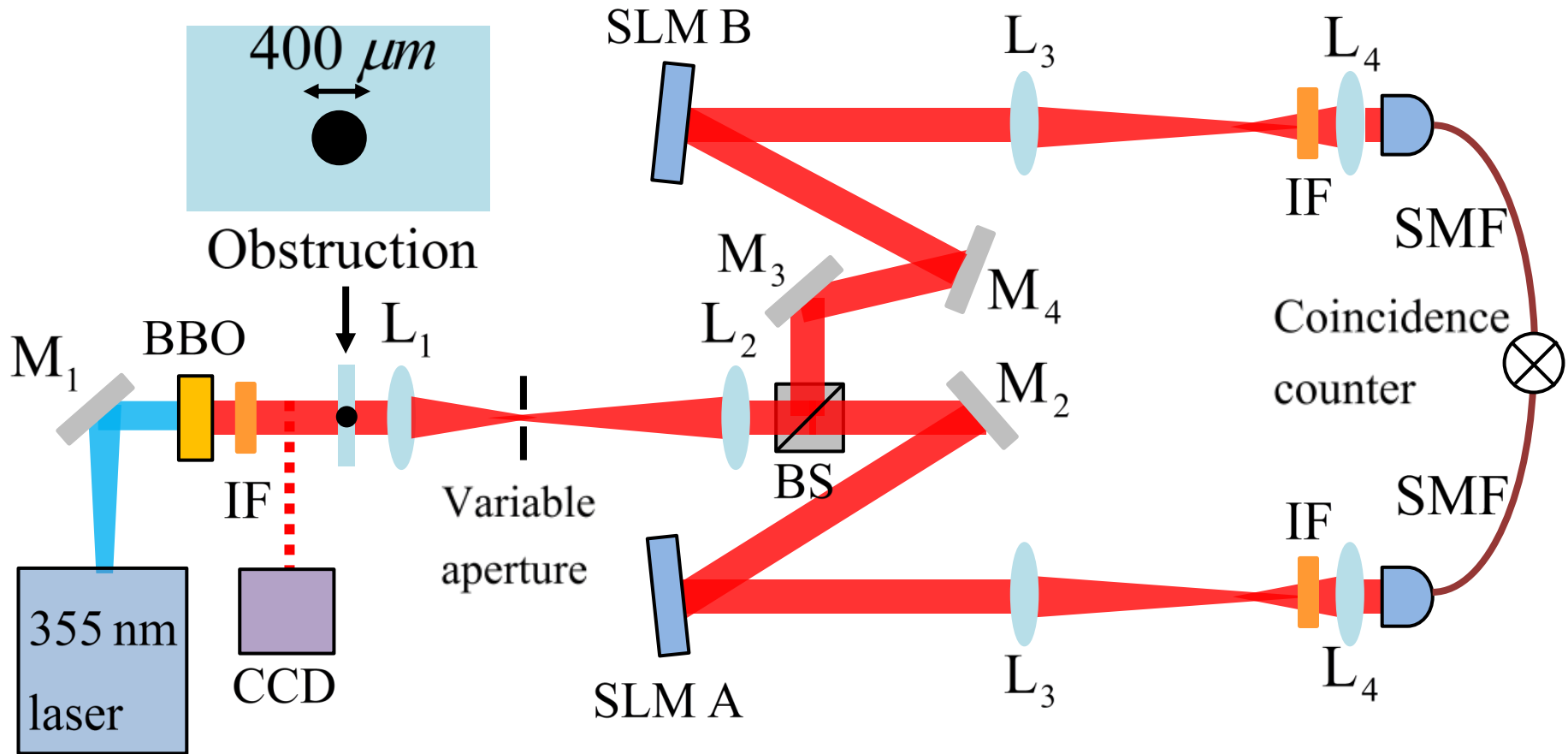
Reconstruction of quantum entanglement?

Reconstruction of quantum entanglement

M. McLaren et al.,2013, To be submitted
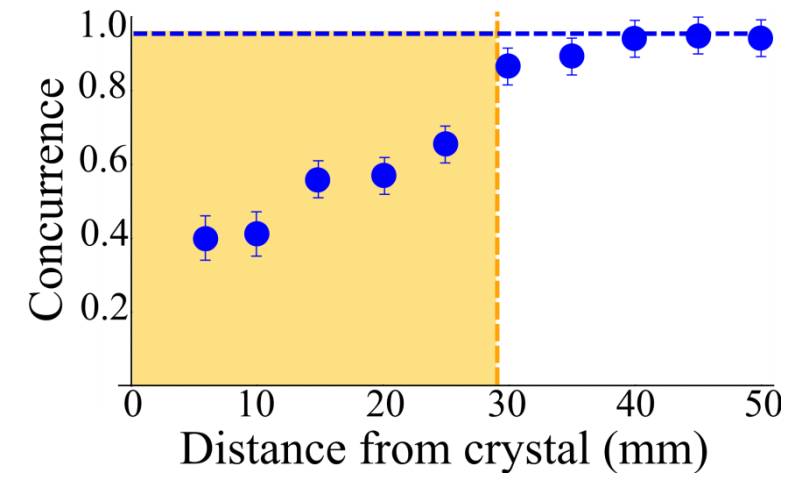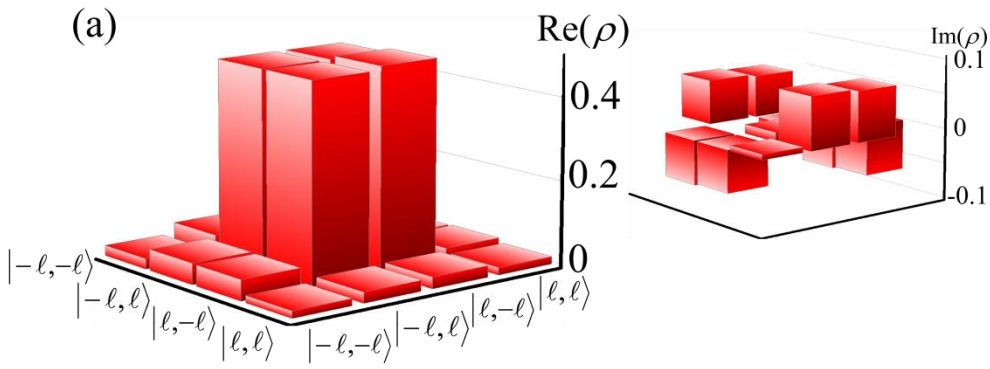
Further potential for Bessel-Gaussian modes in quantum entanglement

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Thank you