Entangling different degree of freedom of optical fields

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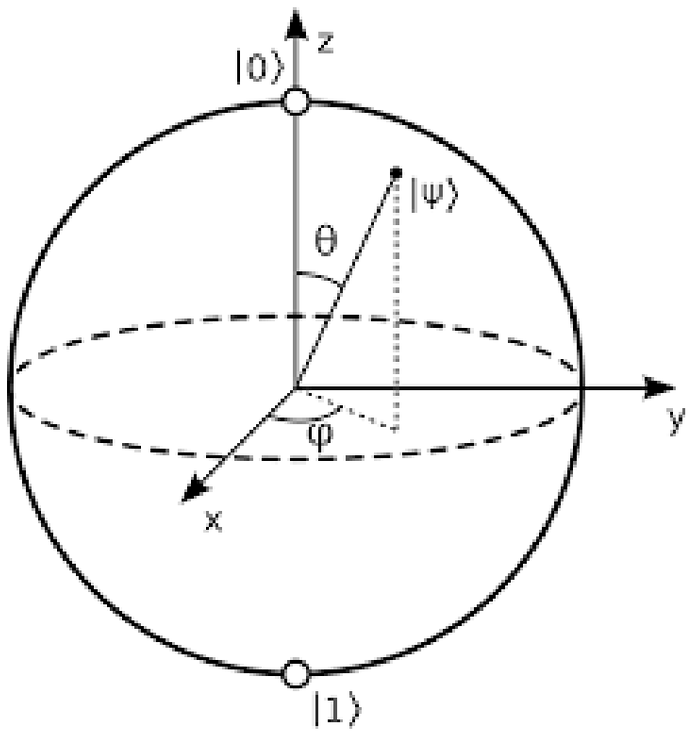
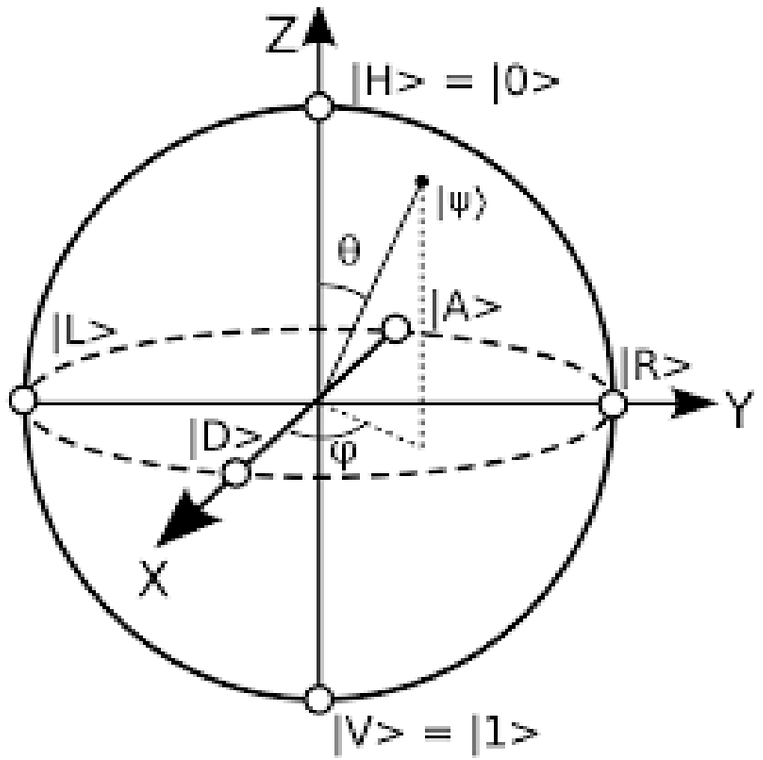
Optical Quantum Information

- Mostly optical entangled states (including qu-bits and CV) exploit polarization as the distinguishability *d.o.f.*.



Bloch sphere for a two-level quantum system



Poincarè sphere

- Polarization accesses 2D Hilbert space for Q-Information

Enlarging the (quantum) computational space

Larger Spaces

- ✓ Multi parties/bit communication
- ✓ Entanglement distribution and multiplexing

- ✓ Large (q)logic alphabets
- ✓ Complex q-simulation

Simulation of topological quantum dynamics with structured light

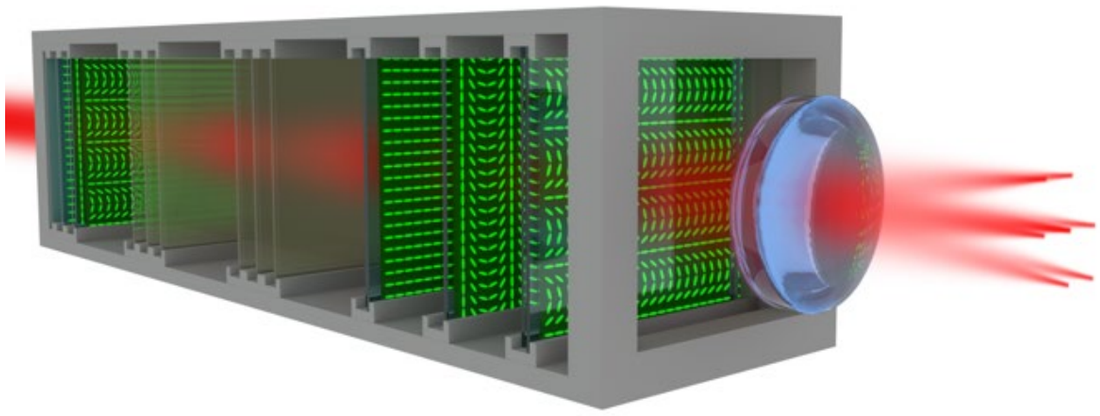
Investigating topological physics in a controlled and simple photonic system

Sci. Adv. **1,** e1500087 (2015)

Nat. Commun. **7,** 11439 (2016)

Nat. Commun. **8,** 15516 (2017)

arXiv:1811.04001 (2018)



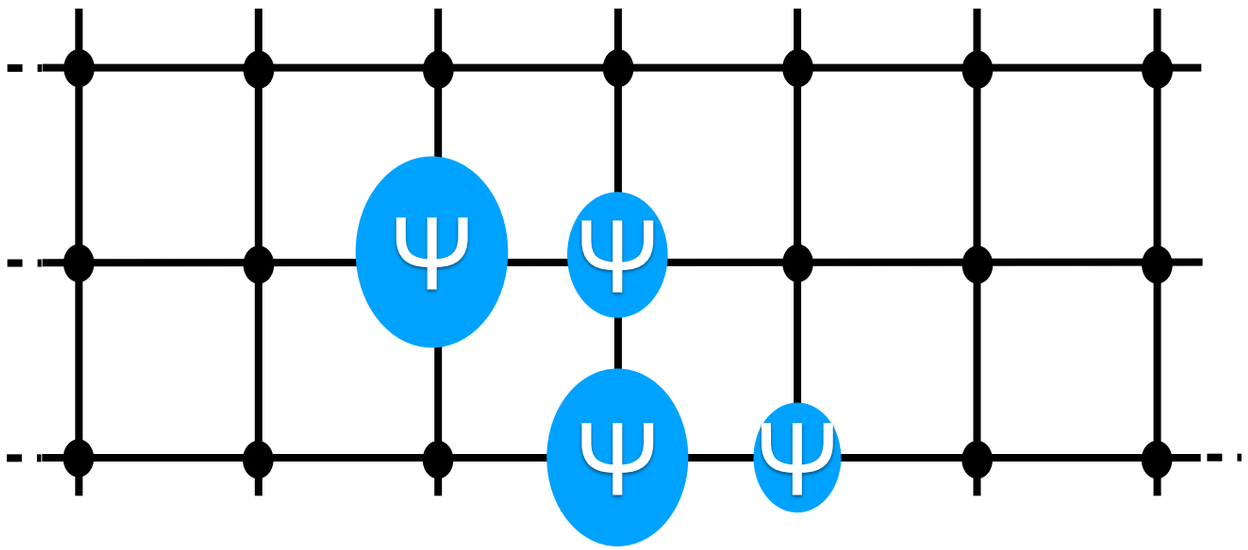
The Nobel Prize in Physics 2016 — Topological Phases of Matter

SLAM group

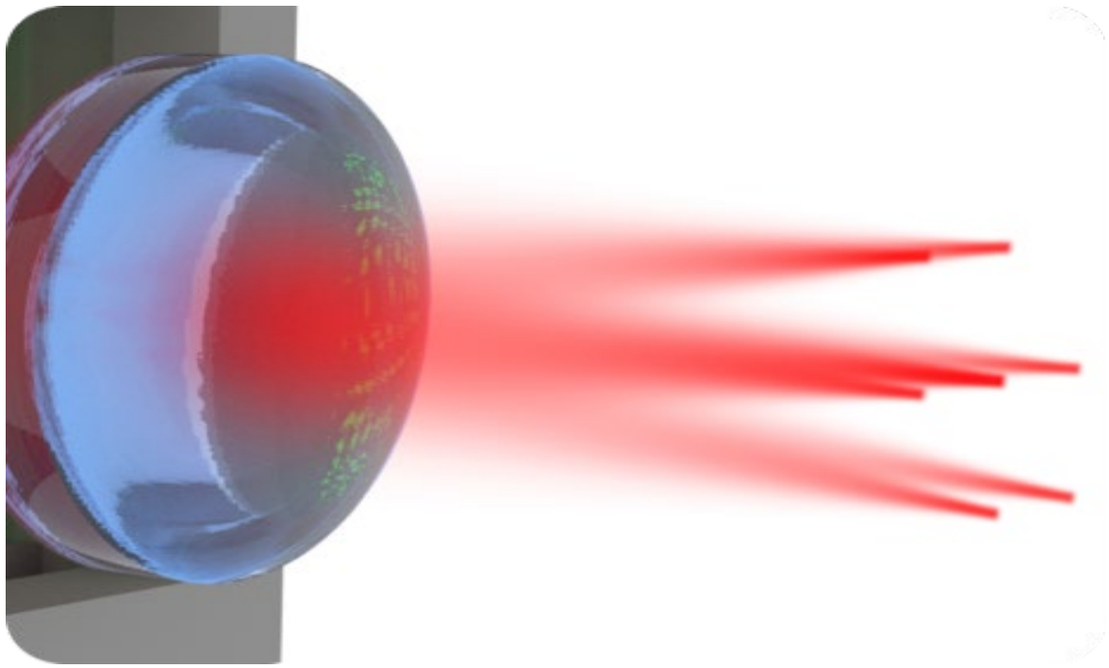
Physics of Structured Light And Matter, and of their interaction

Università degli Studi di Napoli Federico II

Simulate a quantum particle on a 2D lattice provided by spatial modes of light



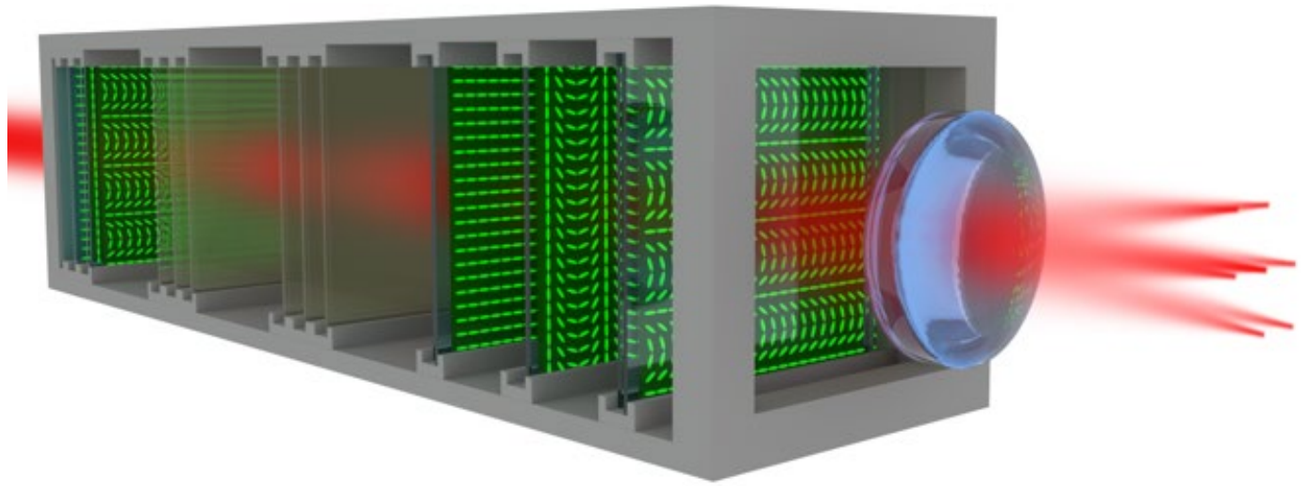
The particle wavefunction spreads over several lattice sites

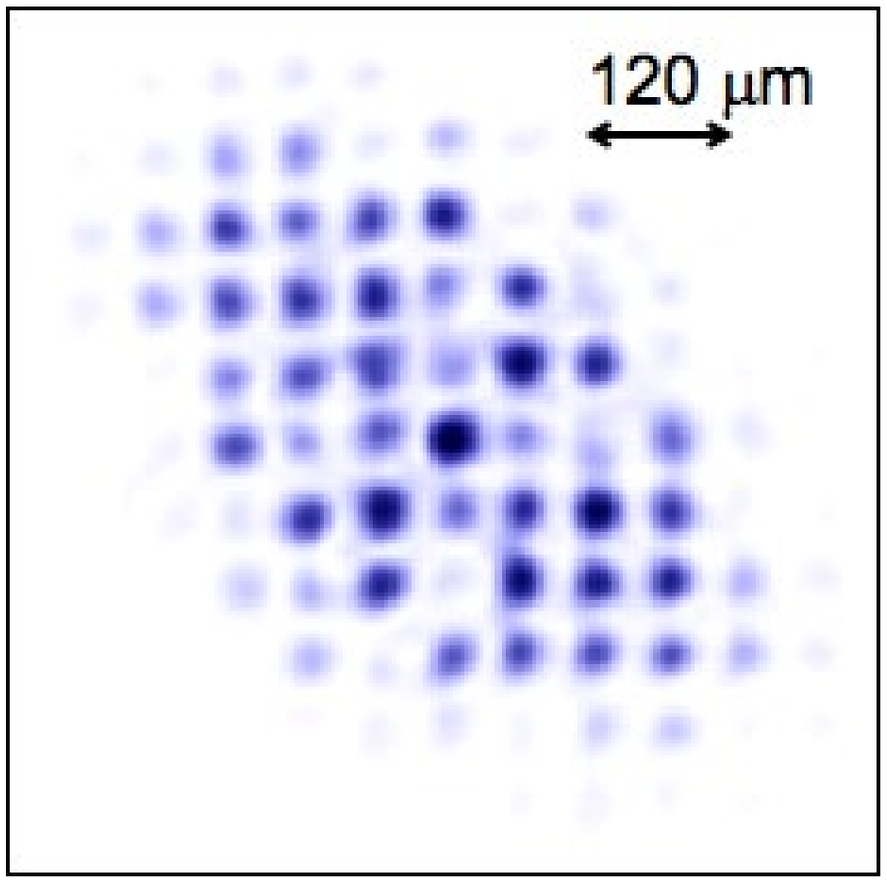


Lattice obtained by considering light modes propagating in slightly tilted directions

Simulation of a quantum walk

Dynamics obtained with spin-orbit interaction in liquid crystal cells

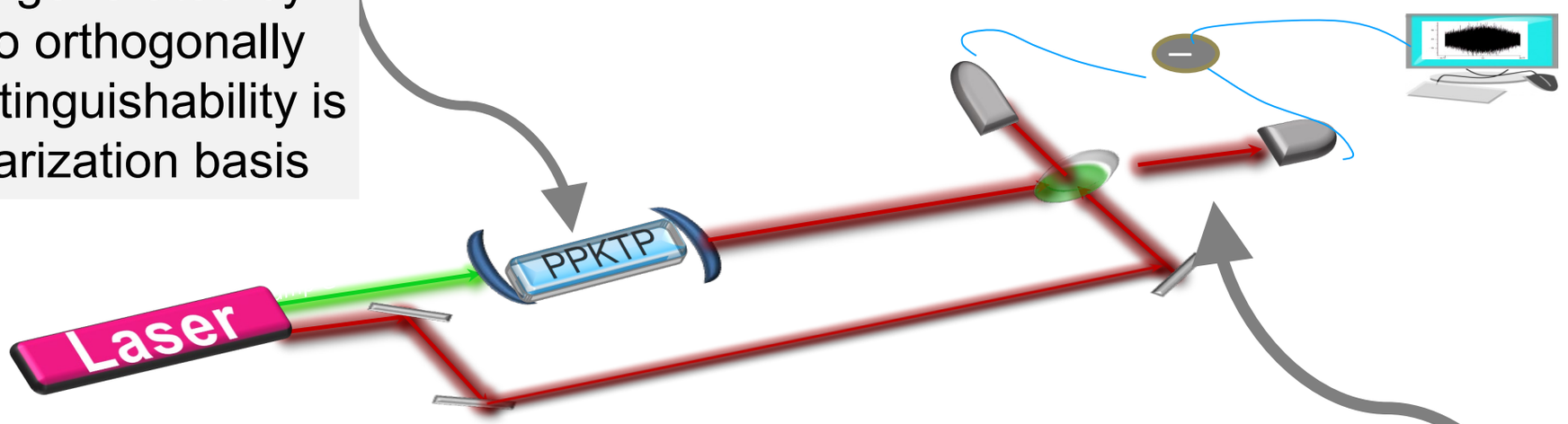




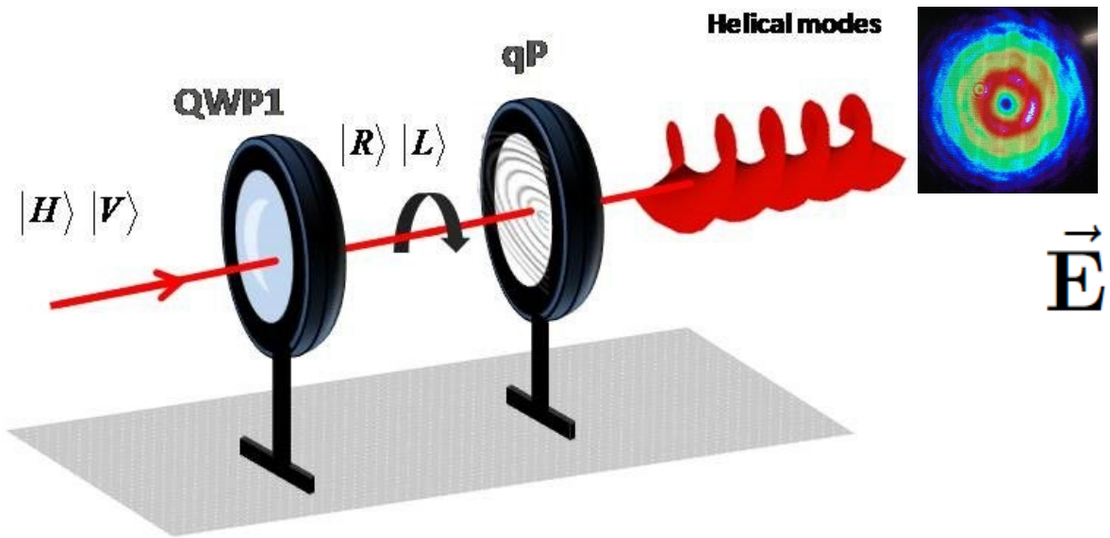
Light intensity is proportional to the probability distribution associated with the single-particle wavefunction

Continuous Variable (CV) among OAM modes

CV entangled states generated by type-II OPOs are two orthogonally polarized modes – distinguishability is guarantee in the polarization basis



The state can be completely characterized by a single homodyne detector scheme



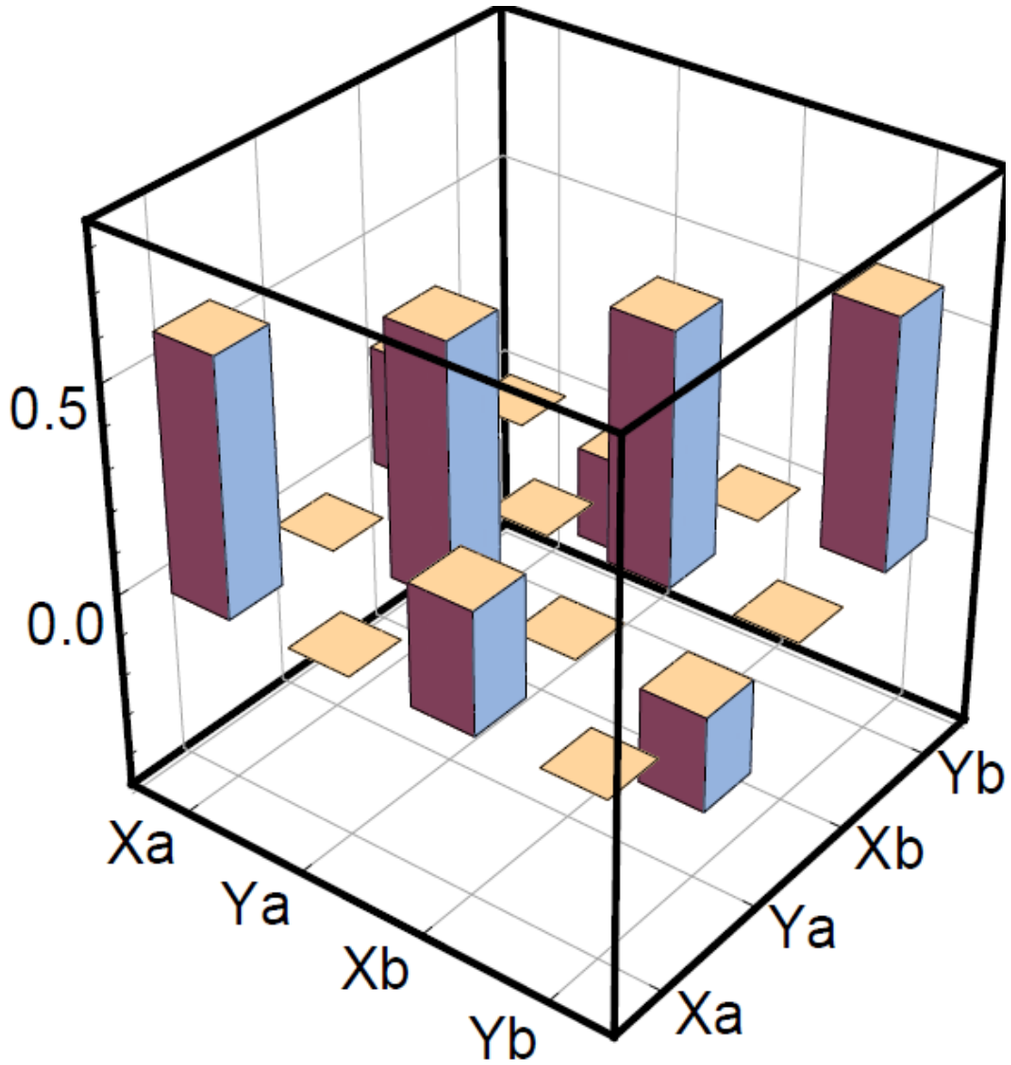
$$\vec{\mathbf{E}}(x,y,z,t) = \vec{\mathbf{E}}_0 A(x,y,z) e^{-i(\omega t - kz)}$$

Spin space (2D) – polarization mode
$\overrightarrow{E_0} \cdot \vec{k} = 0$ the field lies on the plane orthogonal to $\vec{k}$

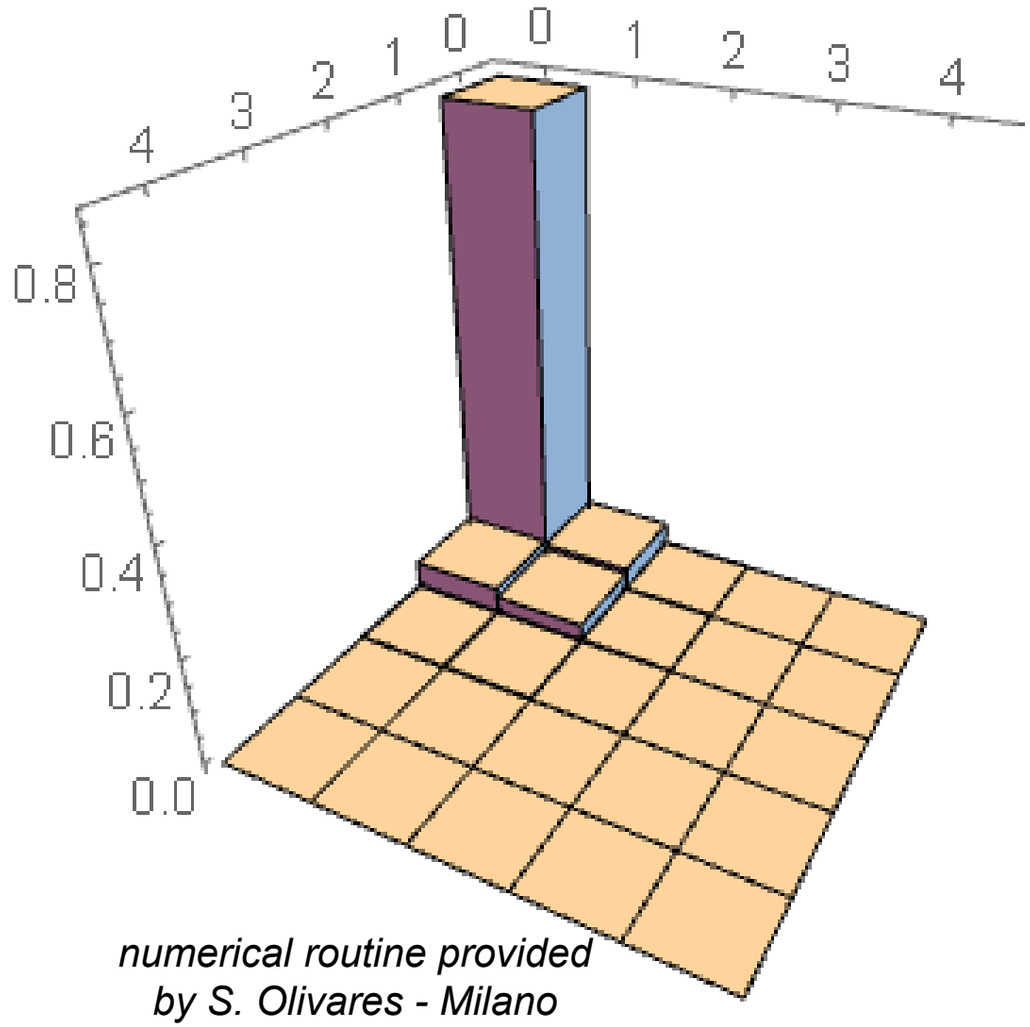
Orbital space (∞-dim) – helical modes
$A = A(x,y,z) \rightarrow A(r,z)e^{im\varphi}$
These are characterized by the helical phase factor $L_z A = m\hbar$

Quantum tomography of entangled OAM modes

Covariance matrix



Joint photon number distribution

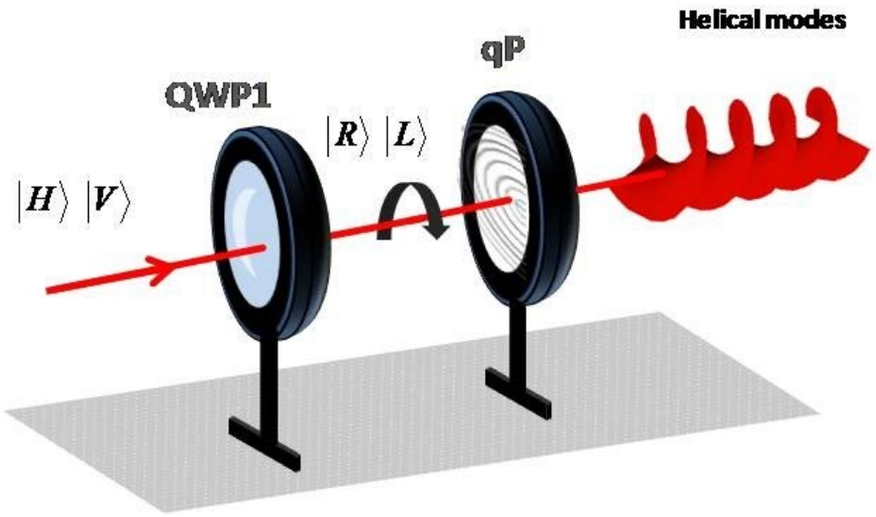


numerical routine provided by S. Olivares - Milano

arXiv:1805.05105

Multimode entangled states

arXiv:1811.08388



q-plate action

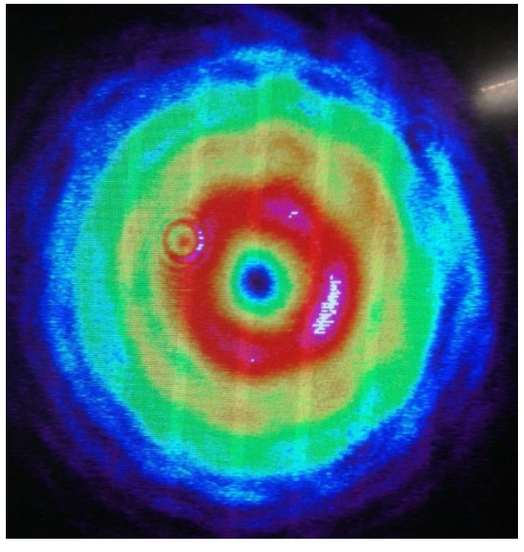
$$E_{L,m} \rightarrow \cos\frac{\delta}{2} E_{L,m} - i \sin\frac{\delta}{2} E_{R,m+2q}$$

$$E_{L,m} \rightarrow \cos\frac{\delta}{2} E_{R,m} - i \sin\frac{\delta}{2} E_{L,m-2q}$$

δ is a tuning adjustable parameter

Tuning δ it is possible to build multimode beams that carry entanglement on every component

$\delta = 0$



$\delta = \frac{\pi}{2}$