The OSA Quantum Computing and Communication Technical Group Welcomes You!

OSA Quantum Computing and Communication Technical Group

Technical Group Leadership 2019

Roberto de J. León-Montiel
Chair
UNAM, Mexico

Vito Giovanni Lucivero
ICFO, Spain

Veronica Vicuña-Hernandez
ICFO, Spain

Ricardo Tellez-Limon
CICESE, Mexico

Jorge L. Domínguez-Juárez
UNAM, Mexico

OSA
Quantum Computing
and Communication
Technical Group

Technical Group at a Glance

- Focus
  - Theoretical and experimental aspects of quantum computing
  - Quantum communication systems - Cryptography
  - Generation, detection and applications of non-classical light
  - Quantum measurement and quantum control
- Mission
  - To maximize the exchange of information and the creation of networking opportunities for our community
  - Webinars, technical events (workshops, tutorials, poster sessions), outreach activities
  - Interested in presenting your research? Have ideas for TG events? Contact us at TGactivities@osa.org.
- Find us here
  - Website: www.osa.org/OC
  - Facebook: https://www.facebook.com/groups/OSAQuantumCC/

Today's Webinar

OSA Quantum Computing and Communication Technical Group

Quantum Mechanics with Classical Light?

Prof. Andrew Forbes

University of the Witwatersrand, Johannesburg, South Africa.

andrew.forbes@wits.ac.za

Speaker's Short Bio:

Andrew Forbes is a distinguished Professor in the Wits School of Physics and Head of the Structured Light Laboratory. He serves on committees of several international conferences such as, OSA and SPIE. Dr. Forbes is on the editorial boards of Optics Express and J. Optics. He is the founding member for the Photonics Initiative of South Africa, a Fellow of both SPIE and the OSA, and an elected member of the Academy of Science of South Africa. Dr. Forbes won a 2015 national award for his contribution to photonics in Africa.

Quantum mechanics with classical light

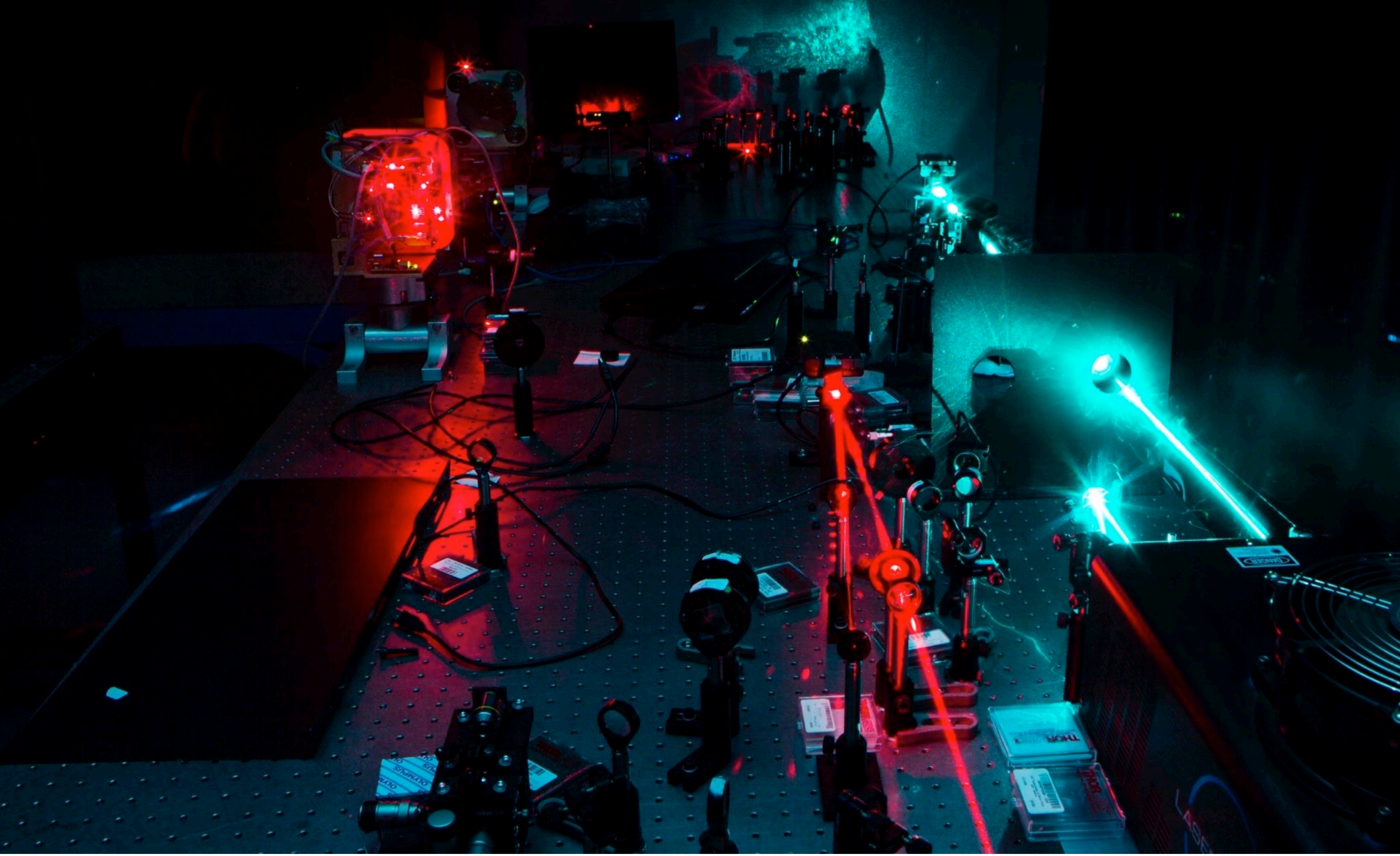
Andrew Forbes
Structured Light Laboratory

WITS
UNIVERSITY


SOUTH AFRICA
Windhoek
BOTSWANA
MOZAMB
NAMIBIA
Kgalagadi Transfrontier Park
Gaborone
Kruger National Park
Nelspruit
Johannesburg
Pretoria
Maput
Soweto
Mbabane
SWAZILAND
Greate St Luci Wetlar
Ladysmith
Upington
Bergville
Bloemfontein
Drakensberg
Port Nolloth
Maseru
Durban
LESOTHO
SOUTH AFRICA
Port St Johns
Lusikisiki
Umtata
Vanrhynsdorp
East London
The Shipwreck Coast
Cape Town
Garden Route
Grahamstown
Mossel Bay
George
Port Elizabeth
Cape of Good Hope
Cape Agulhas
Jeffrey's Bay
0 250 km
0 150 mi

U. Witwatersrand: “Vits”

4 Nobel Laureates
~100 years old

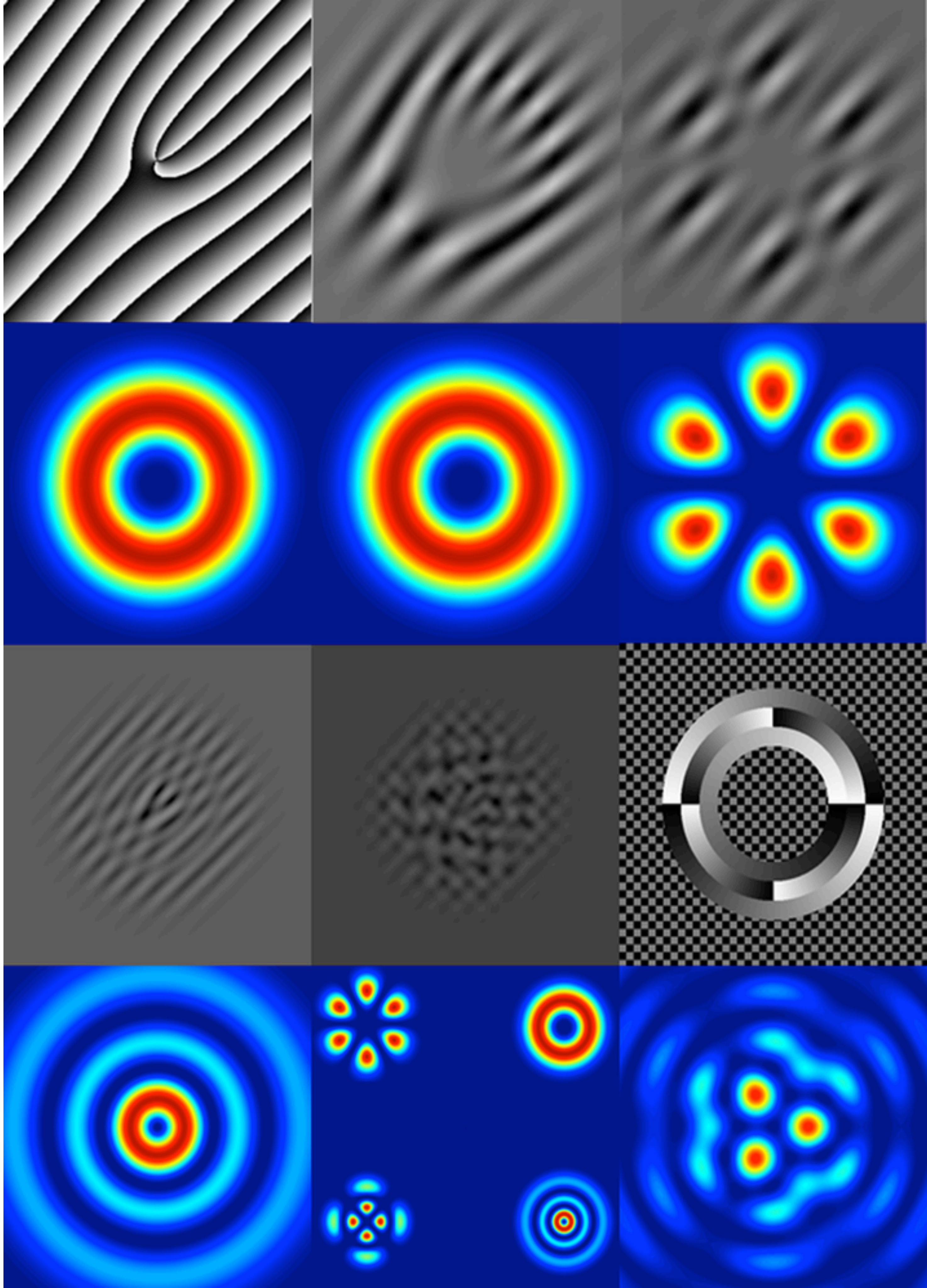


Structured Light

By your method of choice

Any mode can be created

Using complex amplitude modulation on an SLM



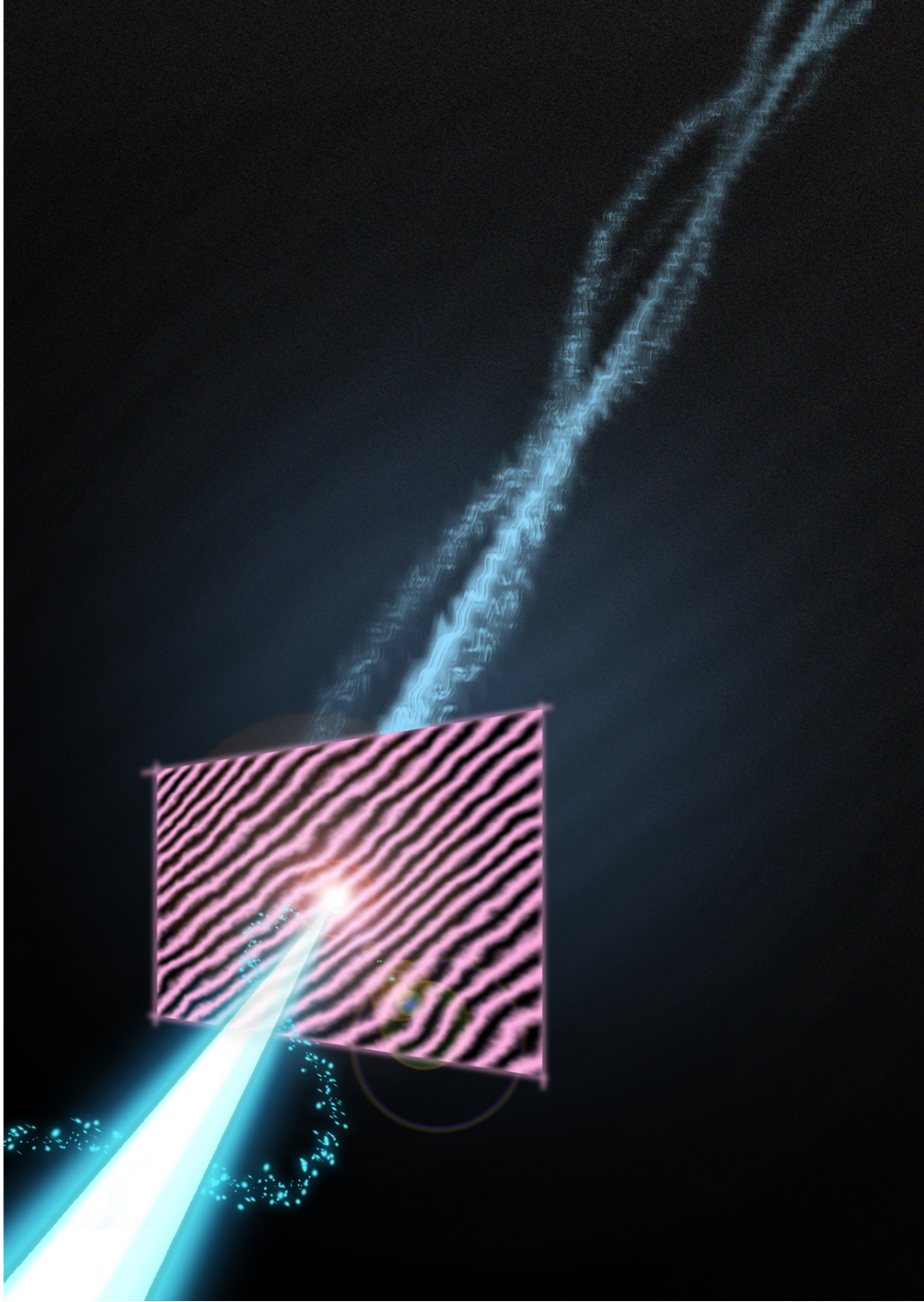
Adv. Opt. Photon. **8**, 200 (2016)

Laser light

Structured light at the source for high-brightness lasers

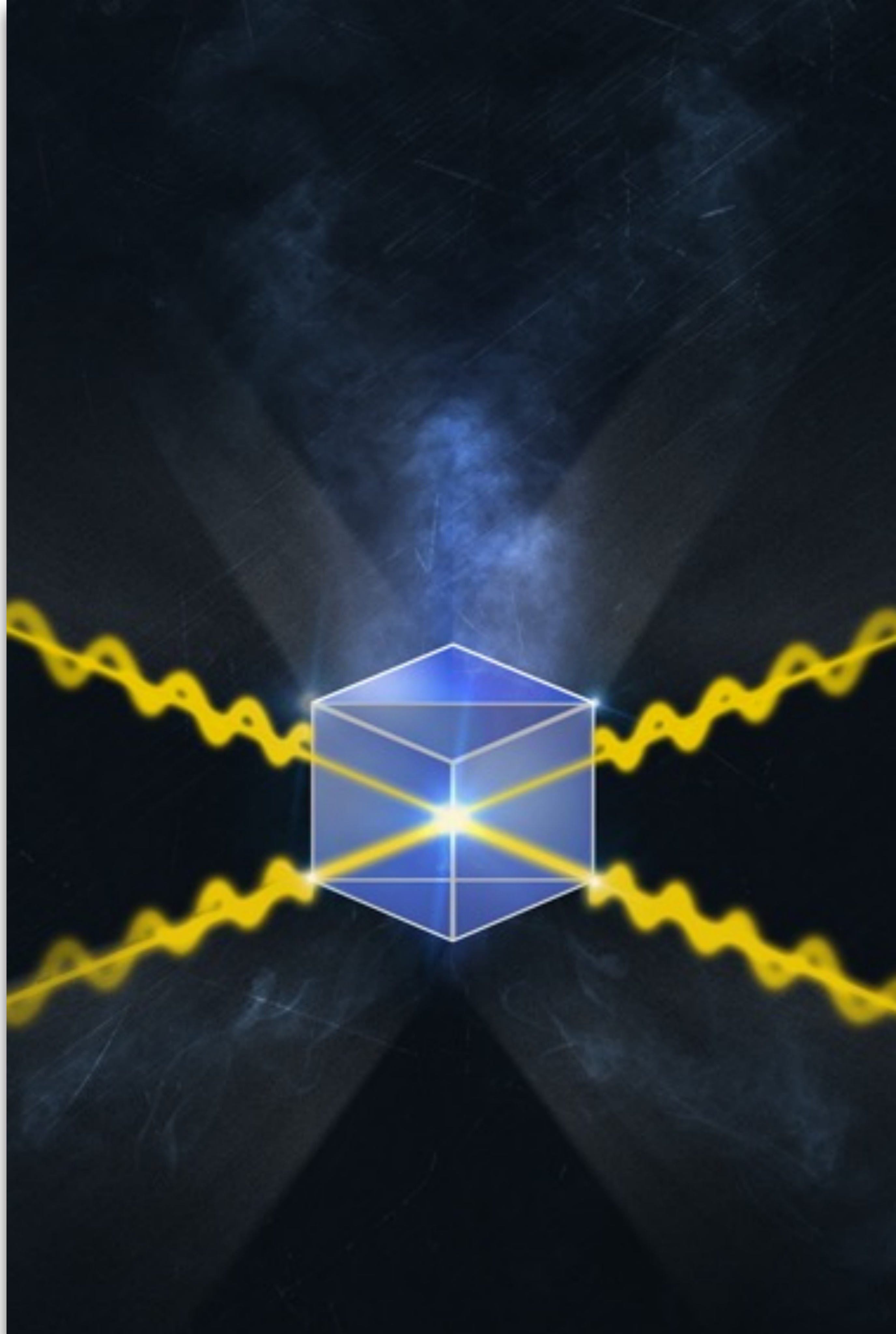
Classical light

For high-bandwidth optical communications and metrology



Quantum light

High-dimensional entanglement
for communication and imaging

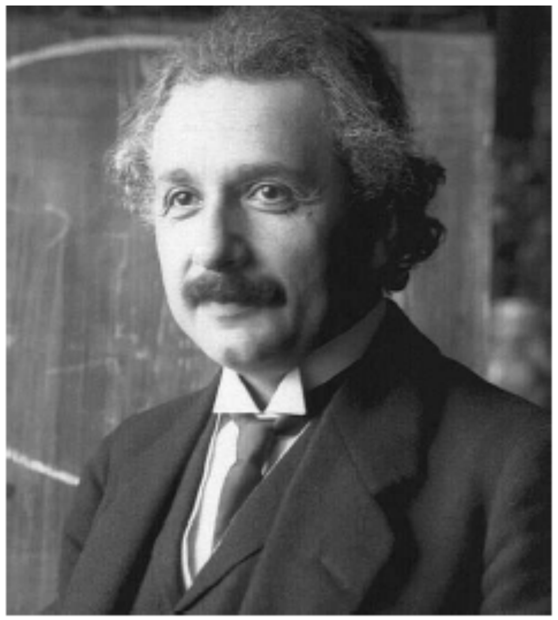


MAY 15, 1935 PHYSICAL REVIEW VOLUME 47

Can Quantum-Mechanical Description of Physical Reality Be Considered Complete?

A. EINSTEIN, B. PODOLSKY AND N. ROSEN, *Institute for Advanced Study, Princeton, New Jersey*

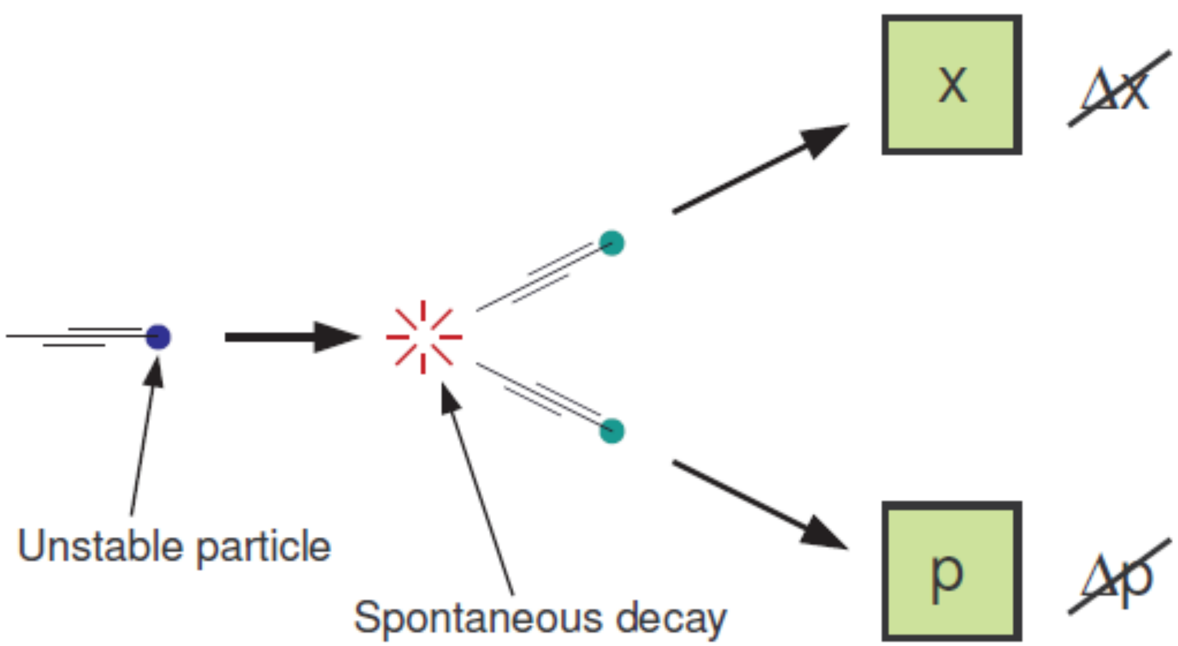
(Received March 25, 1935)



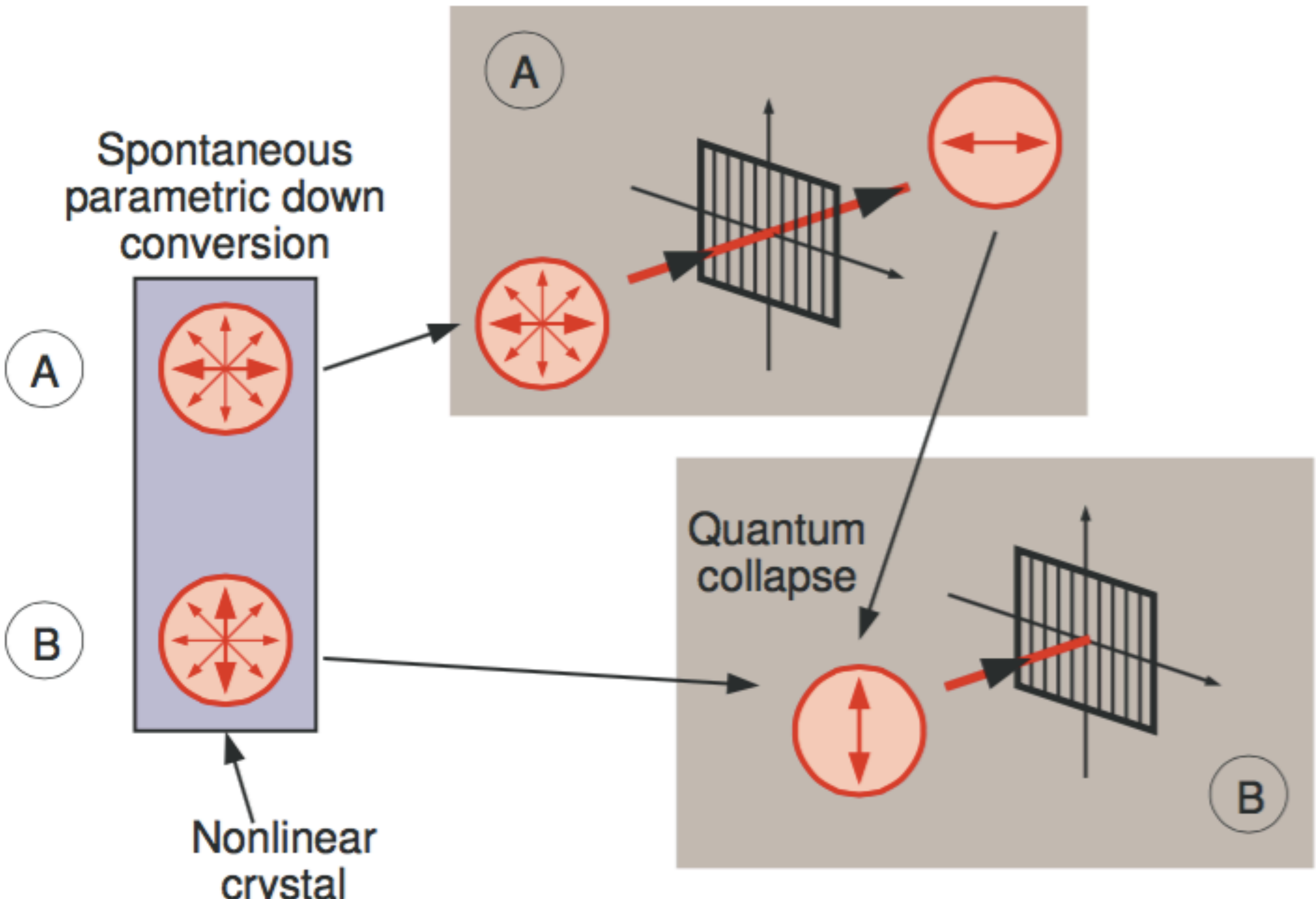
Albert Einstein

Boris Podolsky

Nathan Rosen

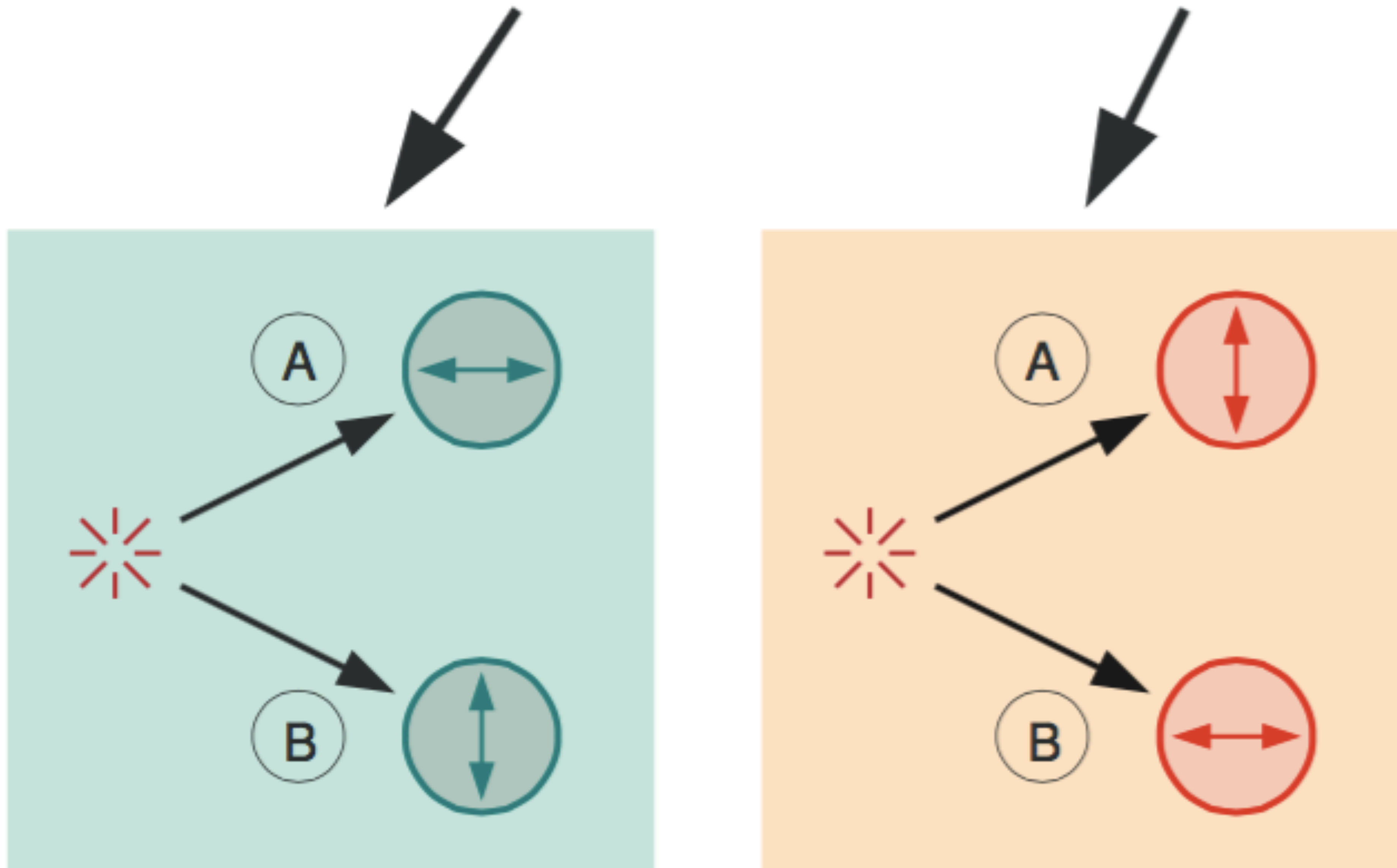


Quantum mechanics:
measurements on one
particle dictate the
state of the other particle.


Spontaneous
parametric down
conversion
A
B
Nonlinear
crystal
A
Quantum
collapse
B

$$|\Psi\rangle = \frac{1}{\sqrt{2}}\,|H\rangle_A\,|V\rangle_B - \frac{1}{\sqrt{2}}\,|V\rangle_A\,|H\rangle_B$$

Reality #1 — Reality #2



We are interested in entangled photonic states

System S

Particle A

Particle B

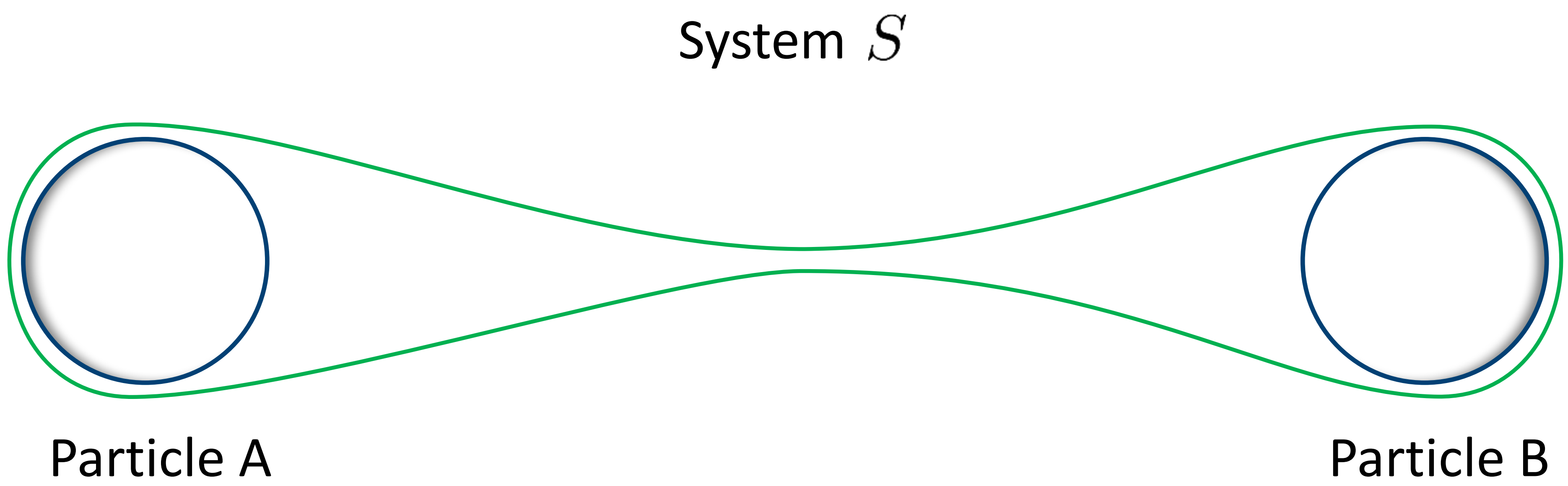
State: $|0\rangle \quad |1\rangle$

State: $|0\rangle \quad |1\rangle$

$$|\Psi\rangle_S = |\text{state}\rangle_A \otimes |\text{state}\rangle_B$$

NO ENTANGLEMENT SEPARABLE STATE

We are interested in entangled photonic states



State: $|0\rangle$ $|1\rangle$

State: $|0\rangle$ $|1\rangle$

$$|\Psi\rangle_S = |\text{state}\rangle_A \otimes |\text{state}\rangle_B$$

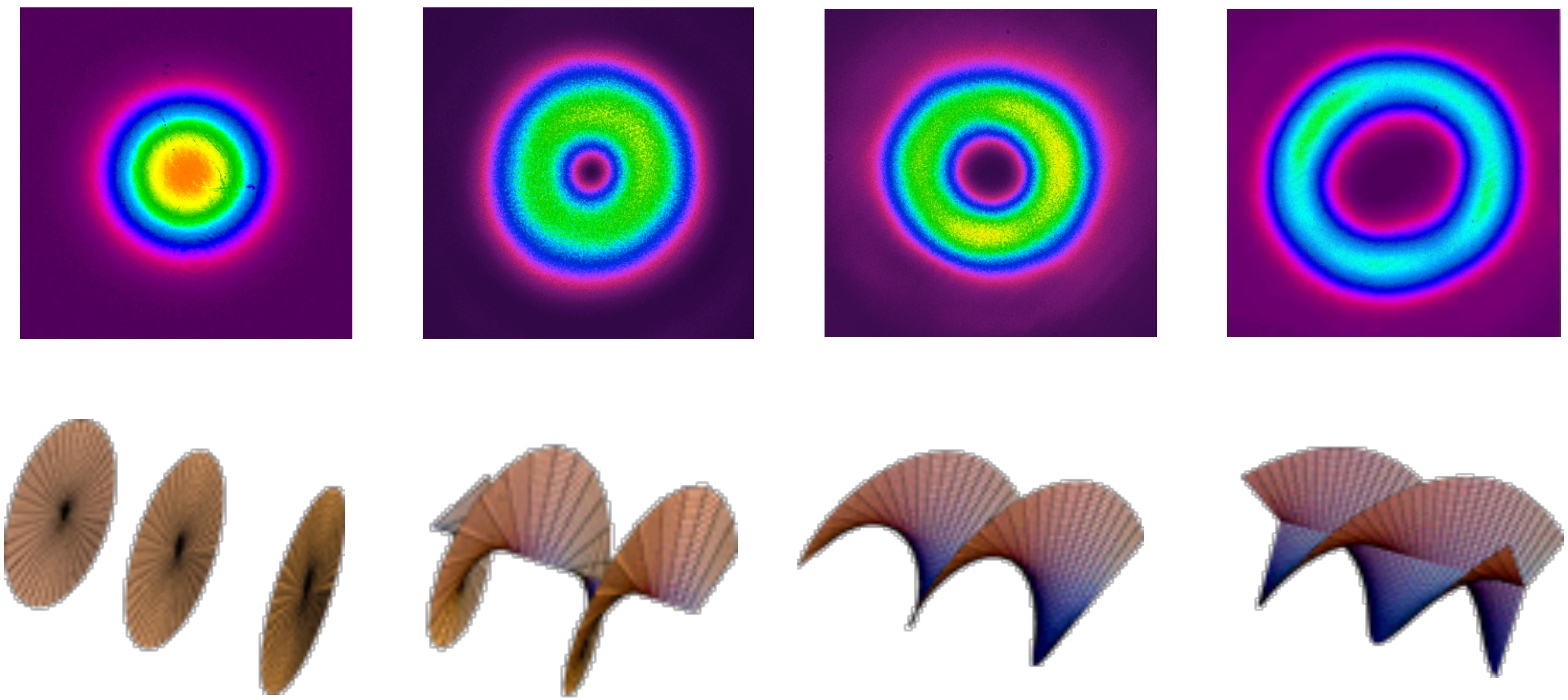
ENTANGLEMENT NON-SEPARABLE STATE

$$|\Psi\rangle_S = |0\rangle_A \otimes |1\rangle_B + |1\rangle_A \otimes |0\rangle_B$$

We will consider OAM as our “pattern”

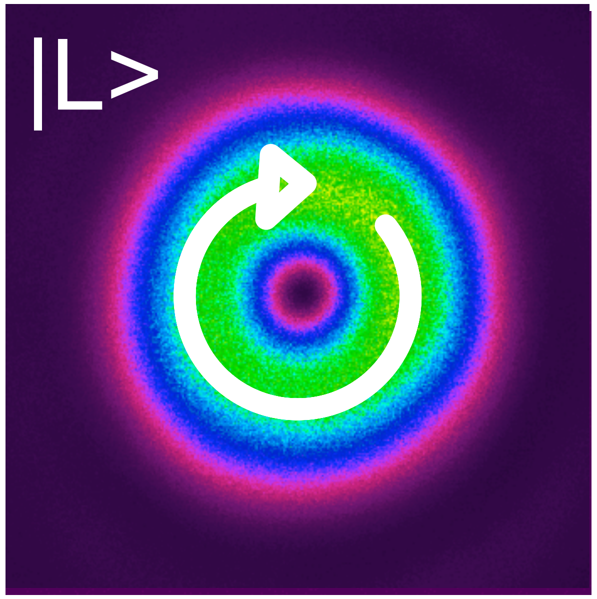
Gaussian beam | Helical wavefront donut beams

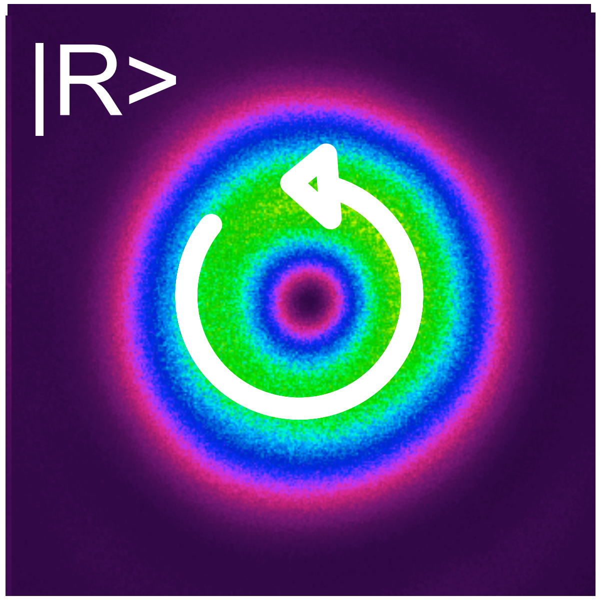
l = 0 | l = 1 | l = 2 | l = 3



We will consider OAM as our “pattern”

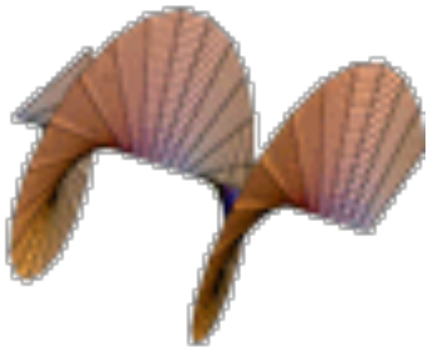
… with polarisation superpositions to create vector vortex beams





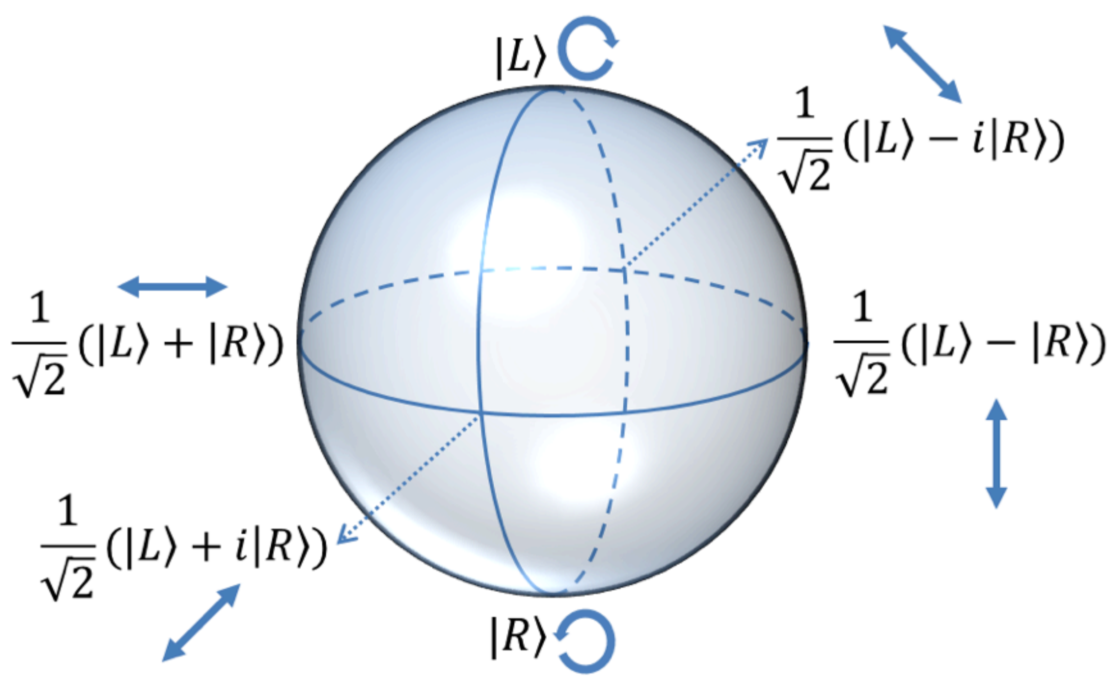
l = -1

l = 1

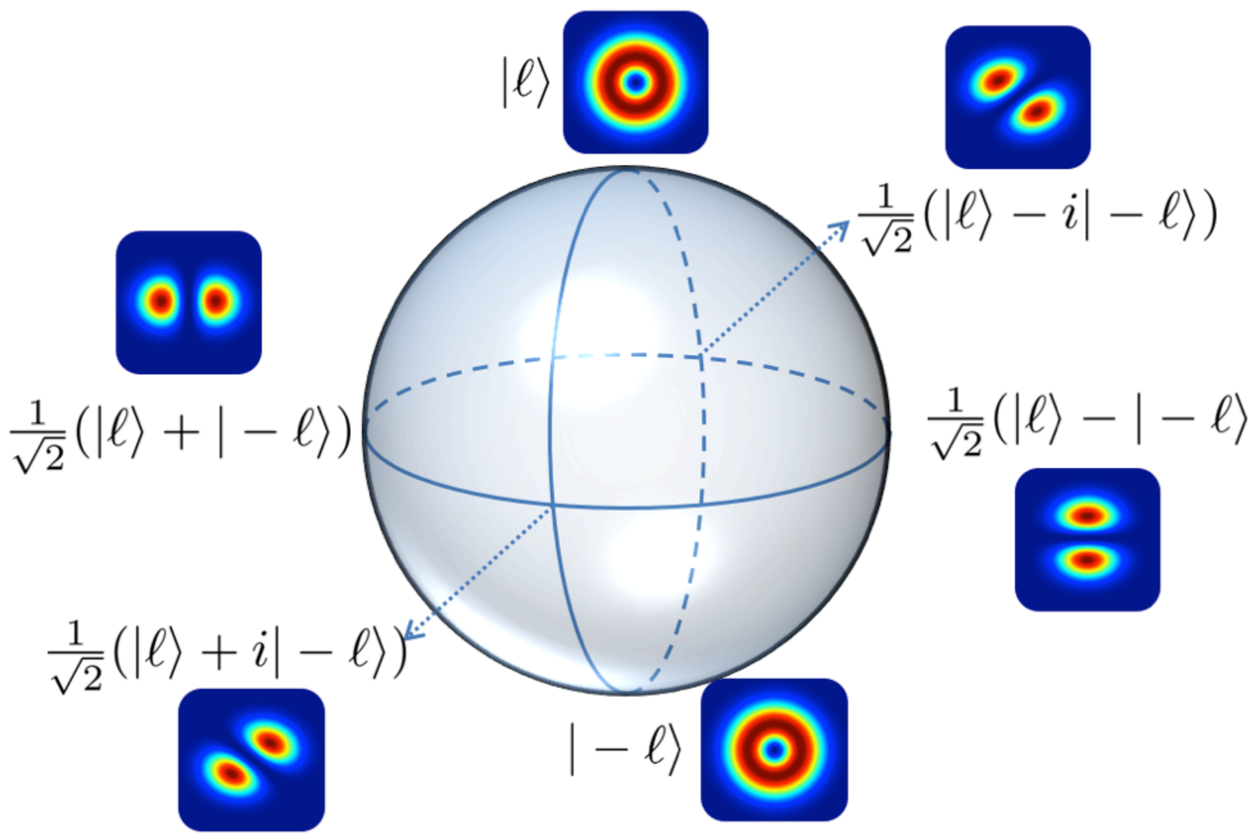


Vector vortex states of light can be mapped on a higher-order Poincaré sphere

$$\alpha|L\rangle + \beta|R\rangle$$



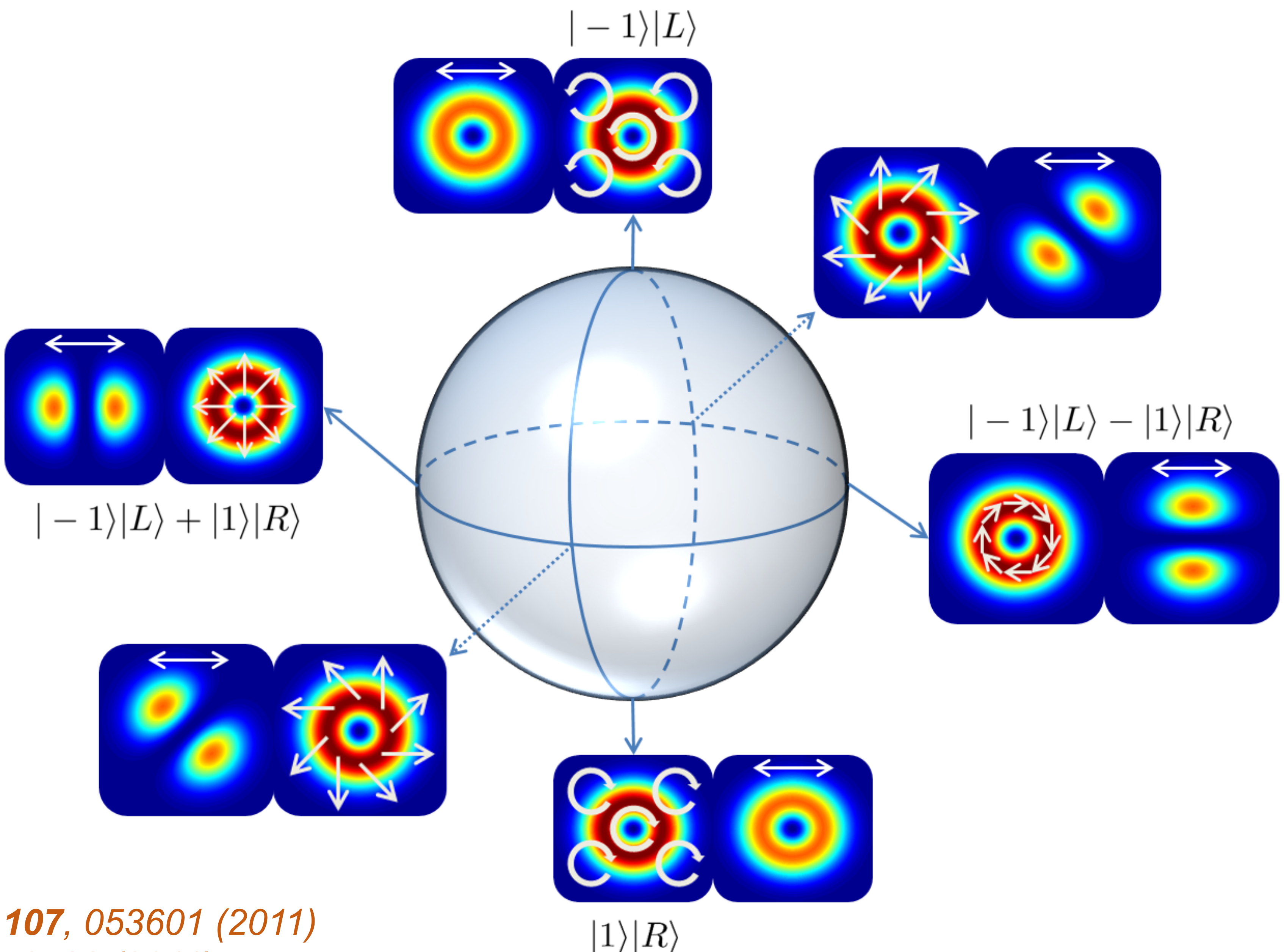
$$\alpha|\ell\rangle + \beta|-\ell\rangle$$



Phys. Rev. Lett. ***107***, *053601 (2011)*
Opt. Express ***19***, *2528 (2011)*

Vector vortex states of light can be mapped on a higher-order Poincaré sphere

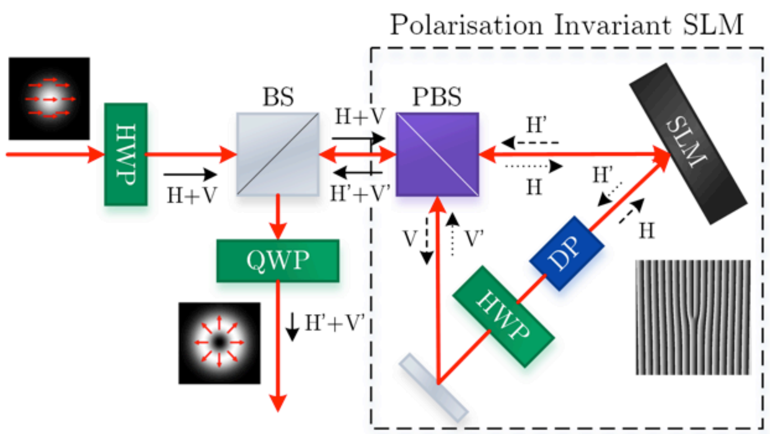
$$|U\rangle = \alpha|-\ell\rangle|L\rangle + \beta|\ell\rangle|R\rangle$$



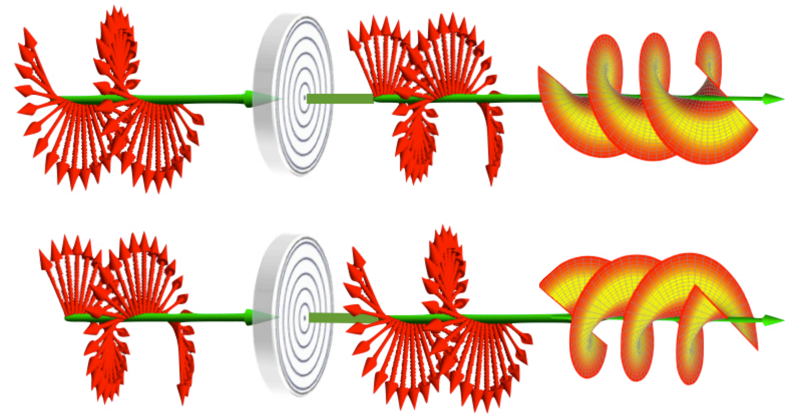
Phys. Rev. Lett. ***107****, 053601 (2011)*
Opt. Express ***19****, 2528 (2011)*

See a recent review: J. Opt. 20, 123001 (2018)

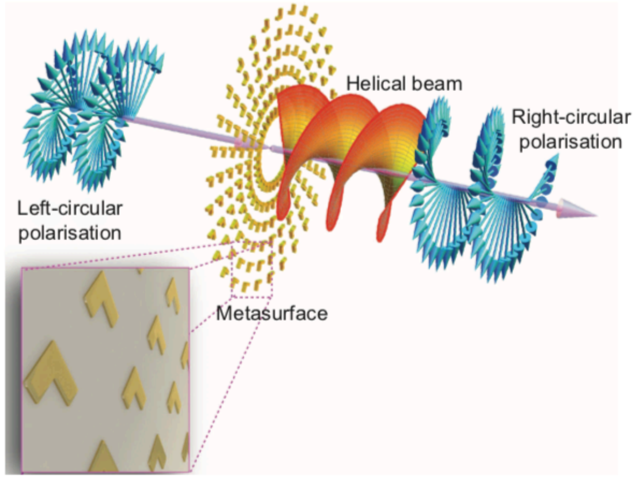
What is your favourite method to create such modes?



Ritsch-Marte: NJP **9**, 78 (2007)

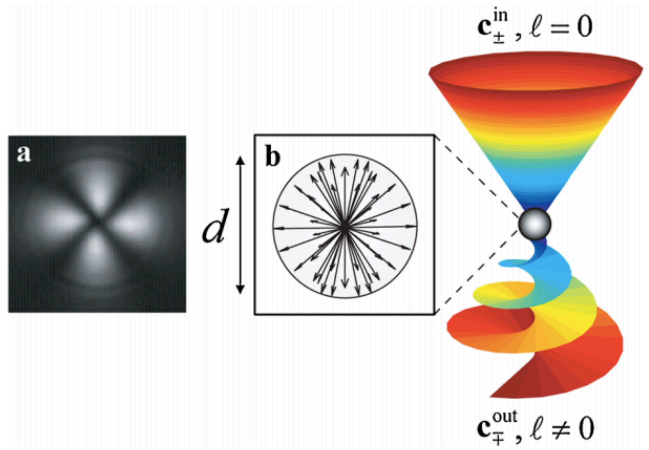


Marrucci: PRL **10**, 327 (2006)

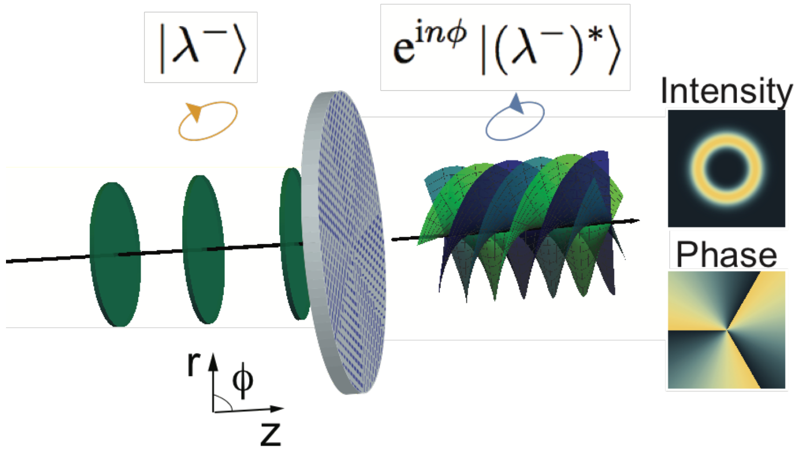


Karimi: LSA **3**, e167 (2014)

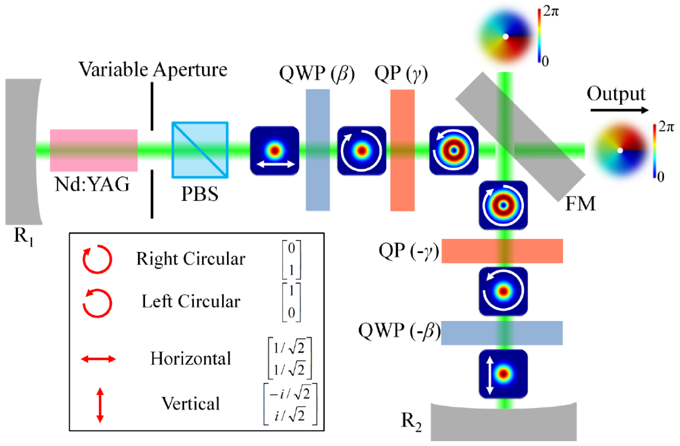
Franke-Arnold: Nat. Commun. **7**, 10654 (2016)



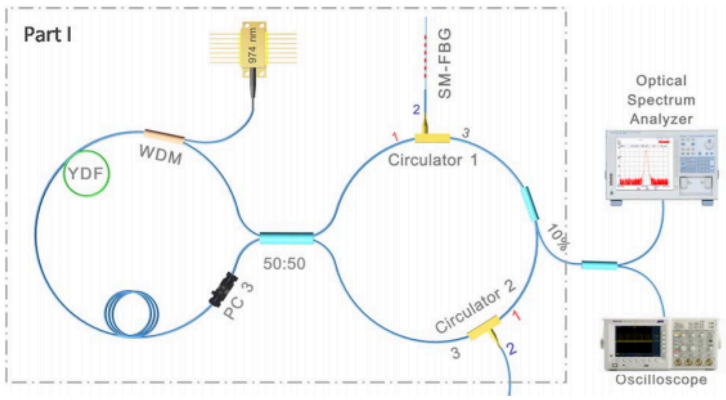
Brasselet: PRL **103**, 103903 (2009)



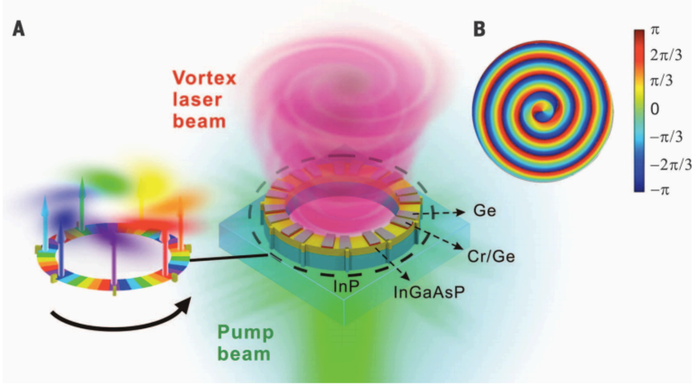
Capasso: Science **358**, 896 (2017)



Forbes: Nature Photonics **10**, 327 (2016)



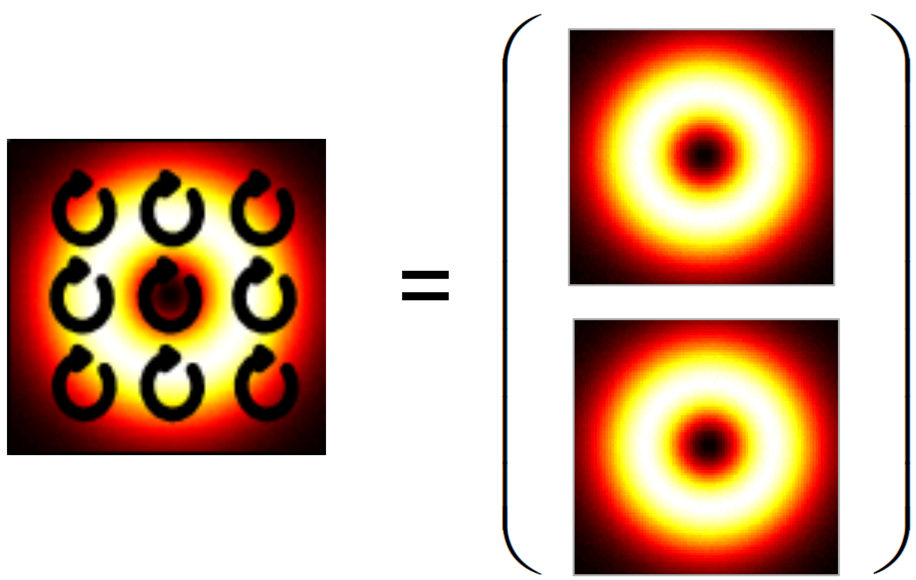
Zhan: OL **40**, 1691 (2015)



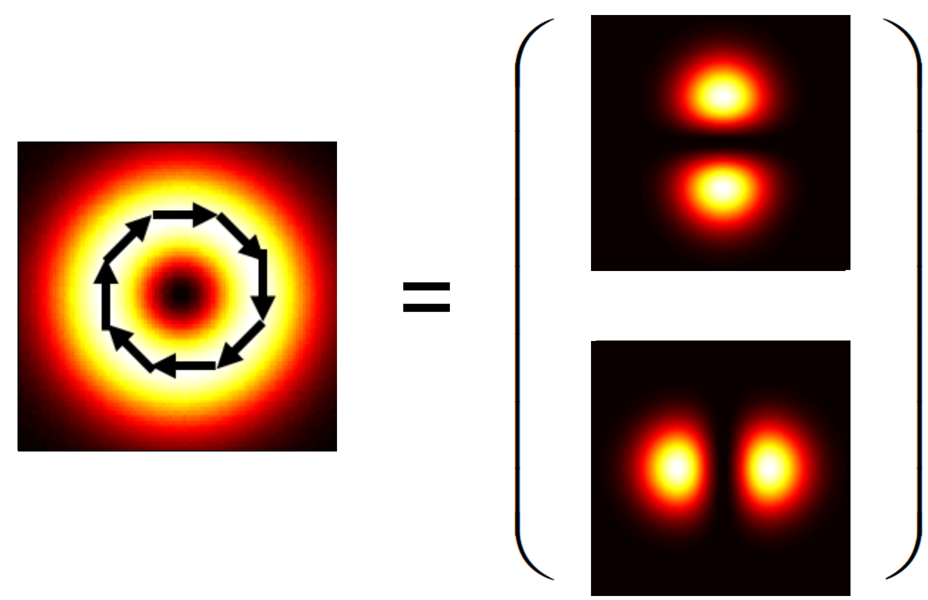
Litchinitser: Science **353**, 464 (2016)

They have the interesting property of
a spatially variant polarisation

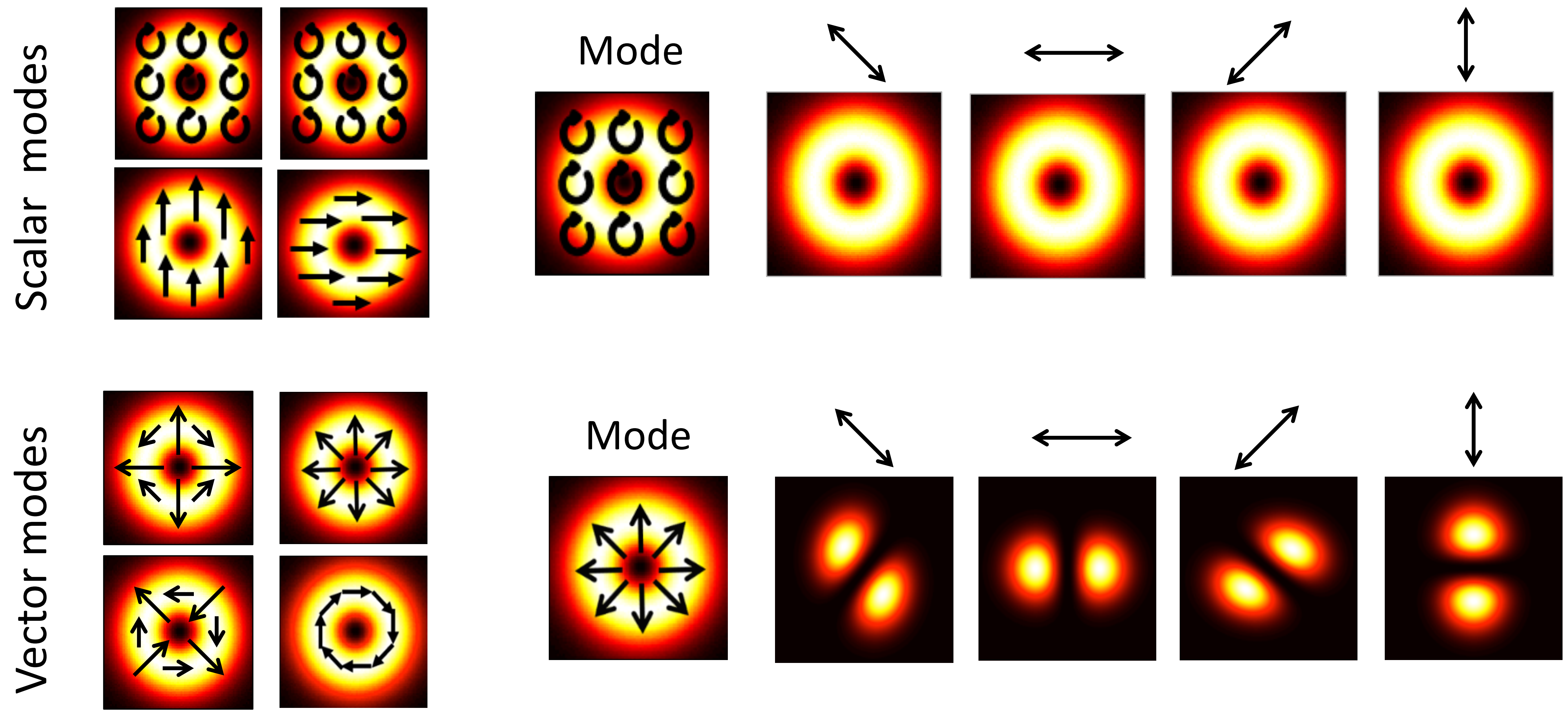
Scalar beams

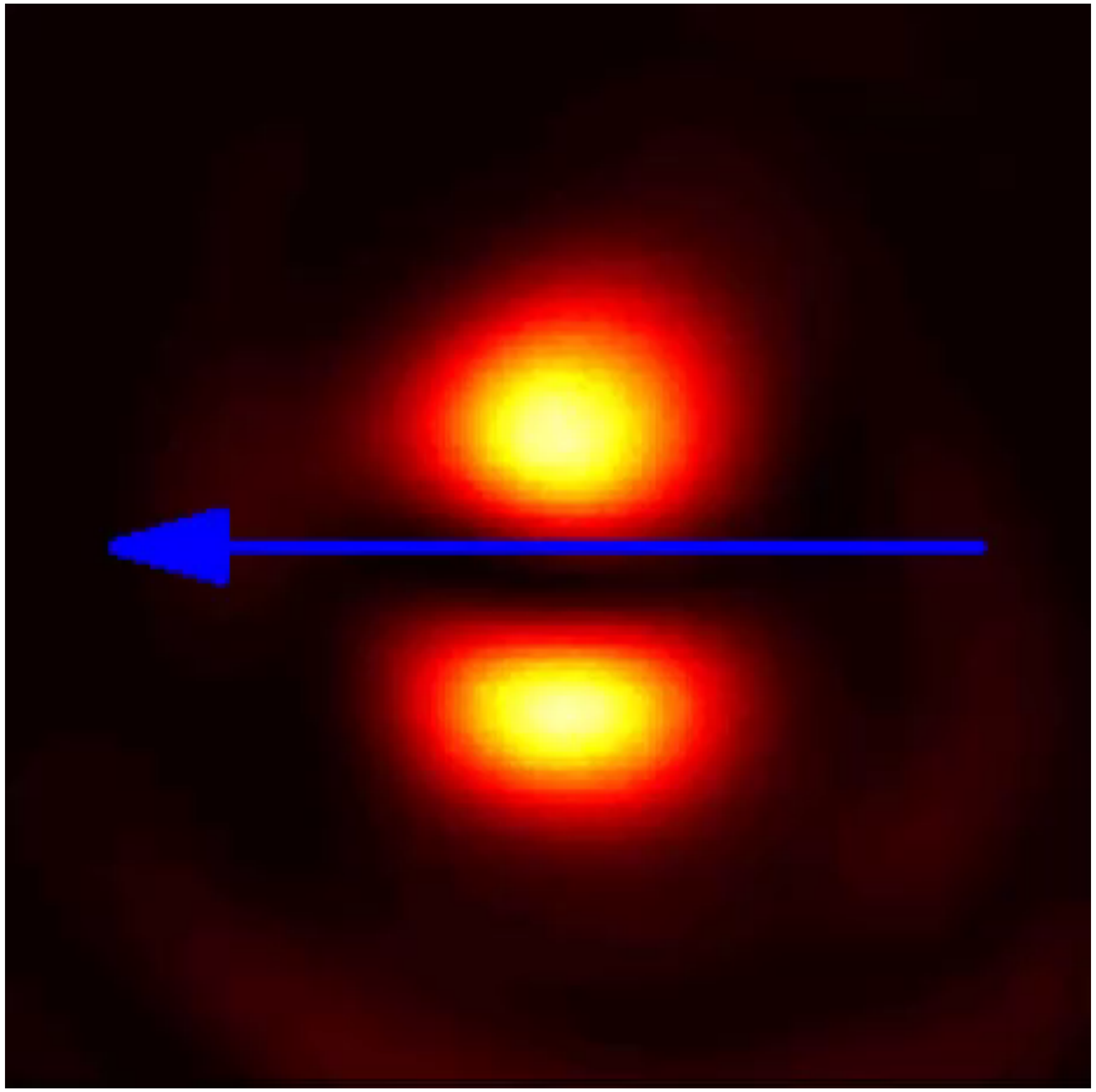


Vector beams

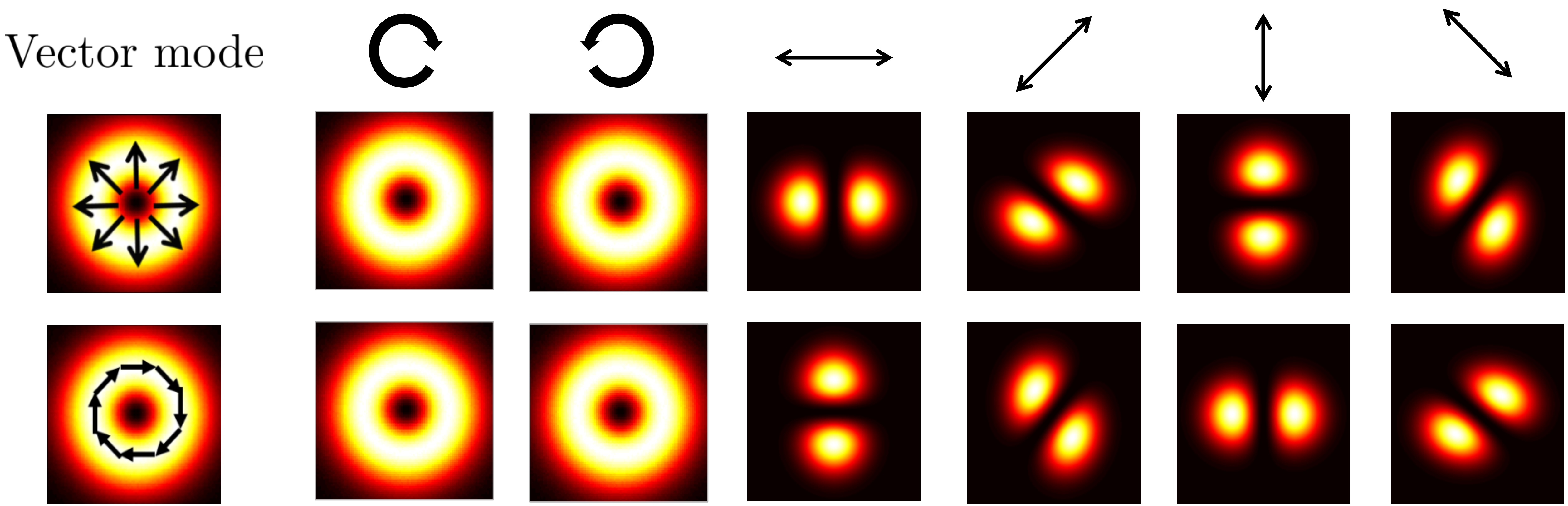


So vector (vortex) beams have inhomogeneous polarisation distributions





Vector vortex modes have inhomogeneous polarisation distributions … non-separable states



Vector vortex beam

$$|\Psi\rangle = |\ell\rangle_1|R\rangle_2 + |\text{-}\ell\rangle_1|L\rangle_2$$

Equivalent?

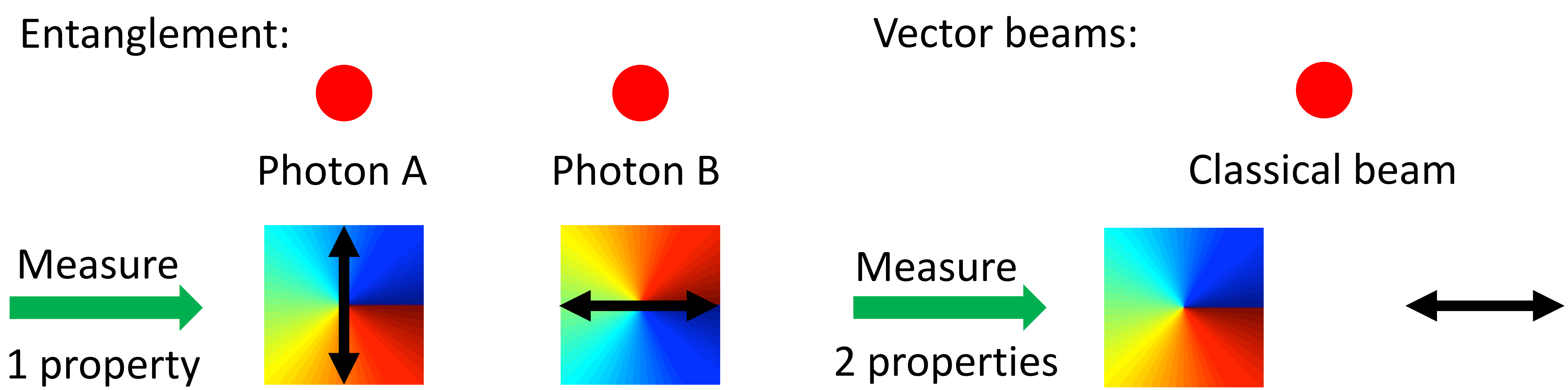
Quantum entangled state

$$|\Psi\rangle = |\ell\rangle_1|\text{-}\ell\rangle_2 + |\text{-}\ell\rangle_1|\ell\rangle_2$$

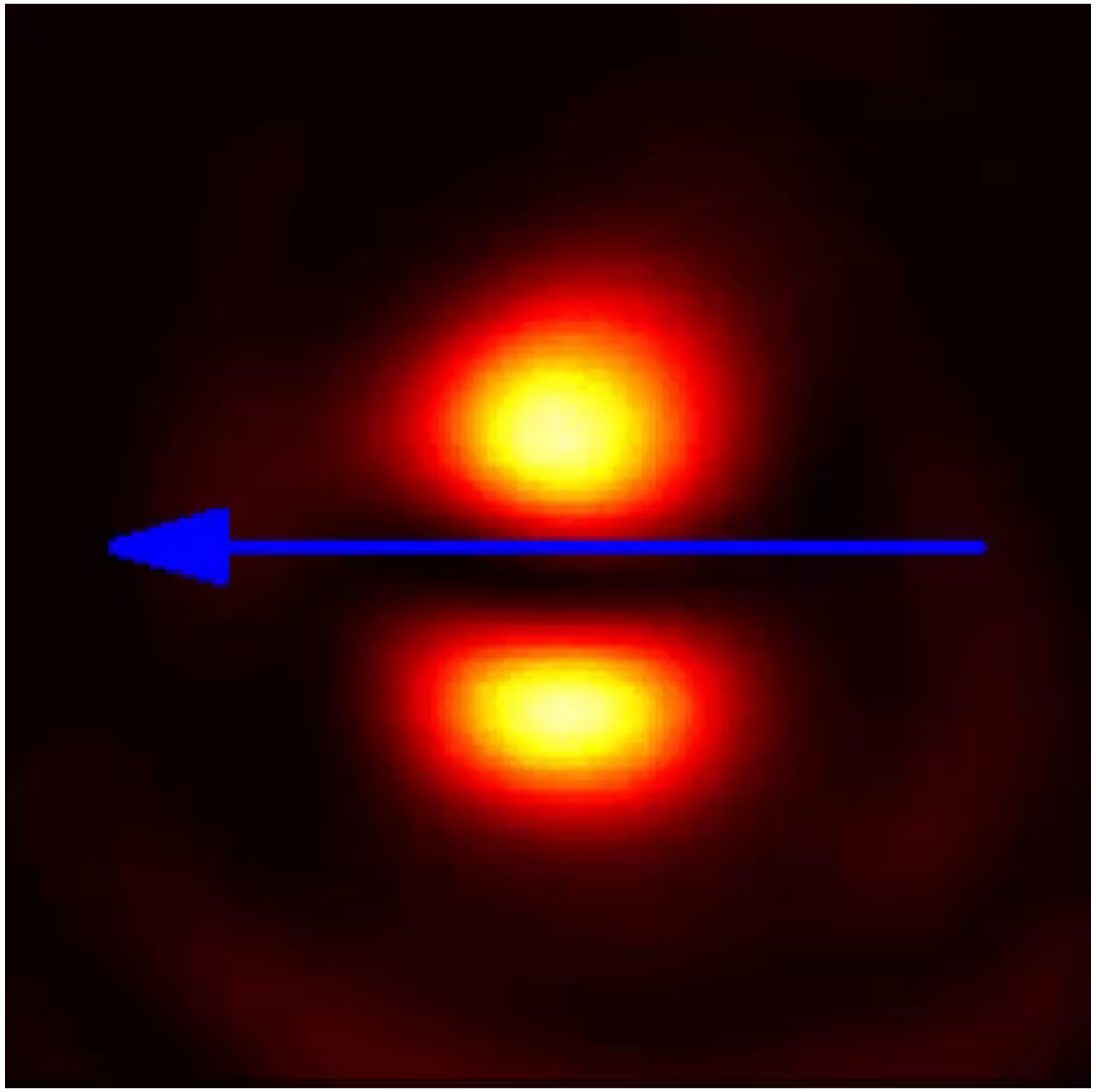
Doesn't this reminds us of quantum entanglement?

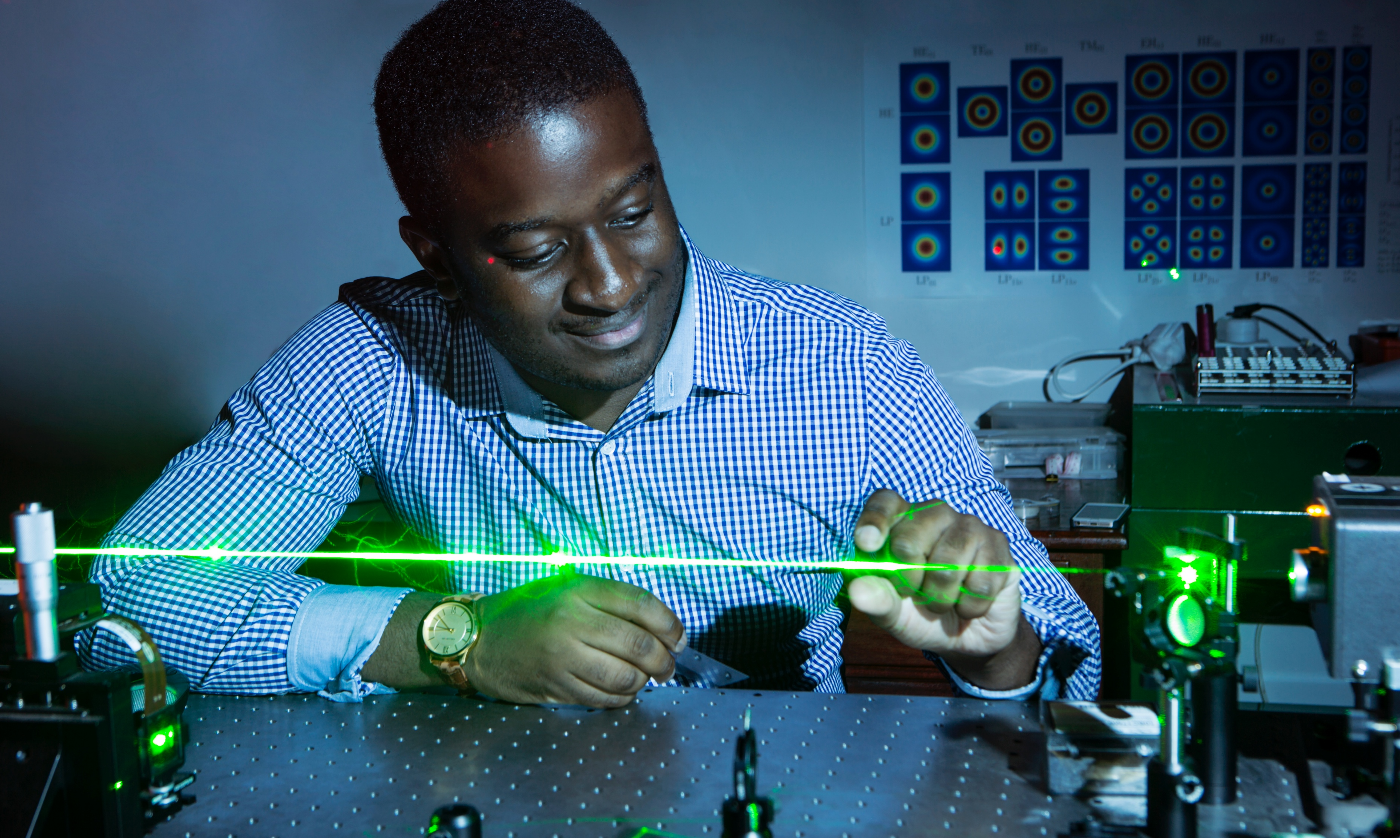
Entanglement: $$|\psi\rangle_{AB} = |\ell\rangle_A |-\ell\rangle_B + |-\ell\rangle_A |\ell\rangle_B$$

Vector beams: $$|\psi\rangle = |\ell\rangle |R\rangle + |-\ell\rangle |L\rangle$$



A measurement on one degree of freedom affects the outcome of the other

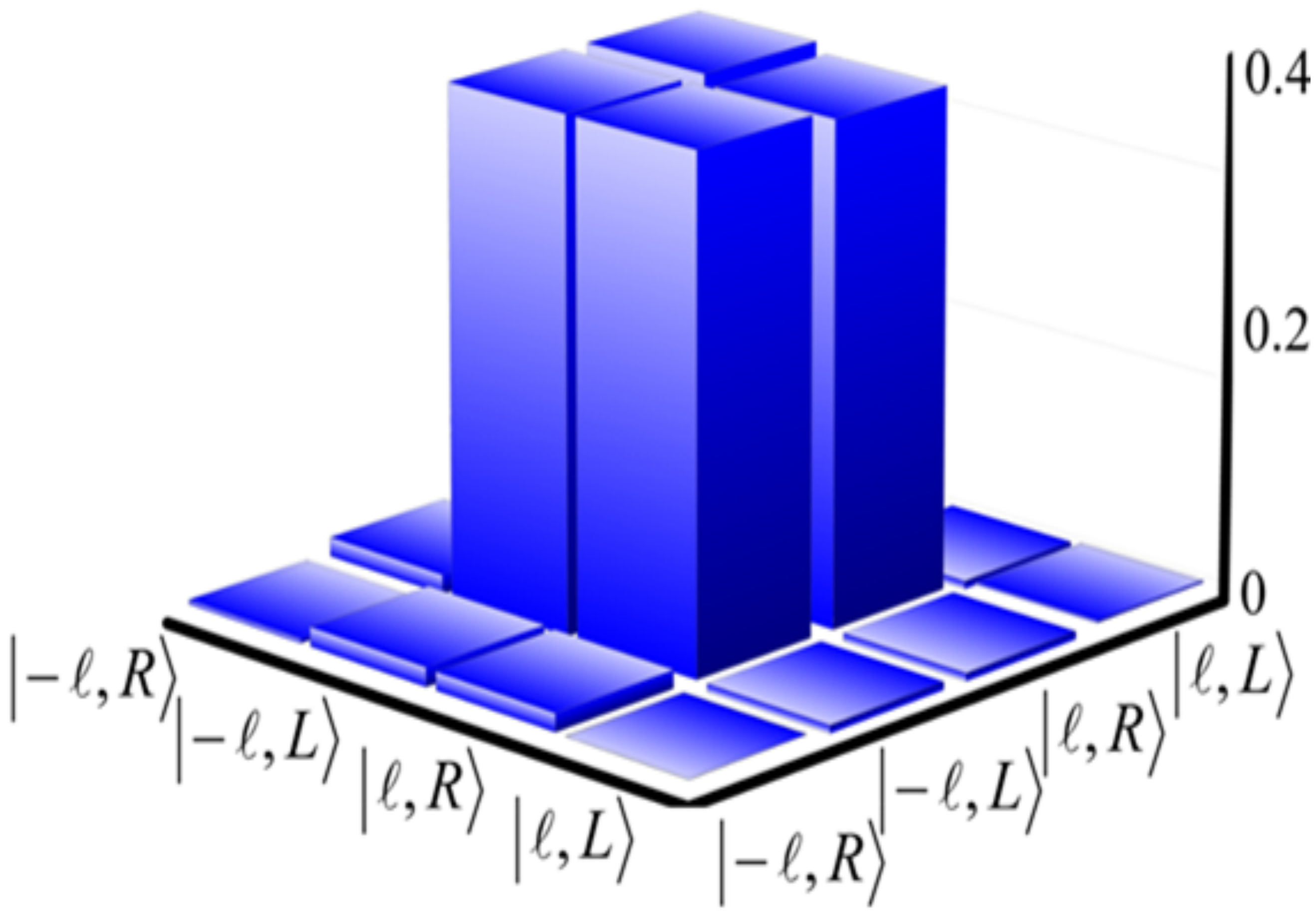




Classical Entanglement

Non-separable states of light

Can we use quantum tools to describe vector beams?

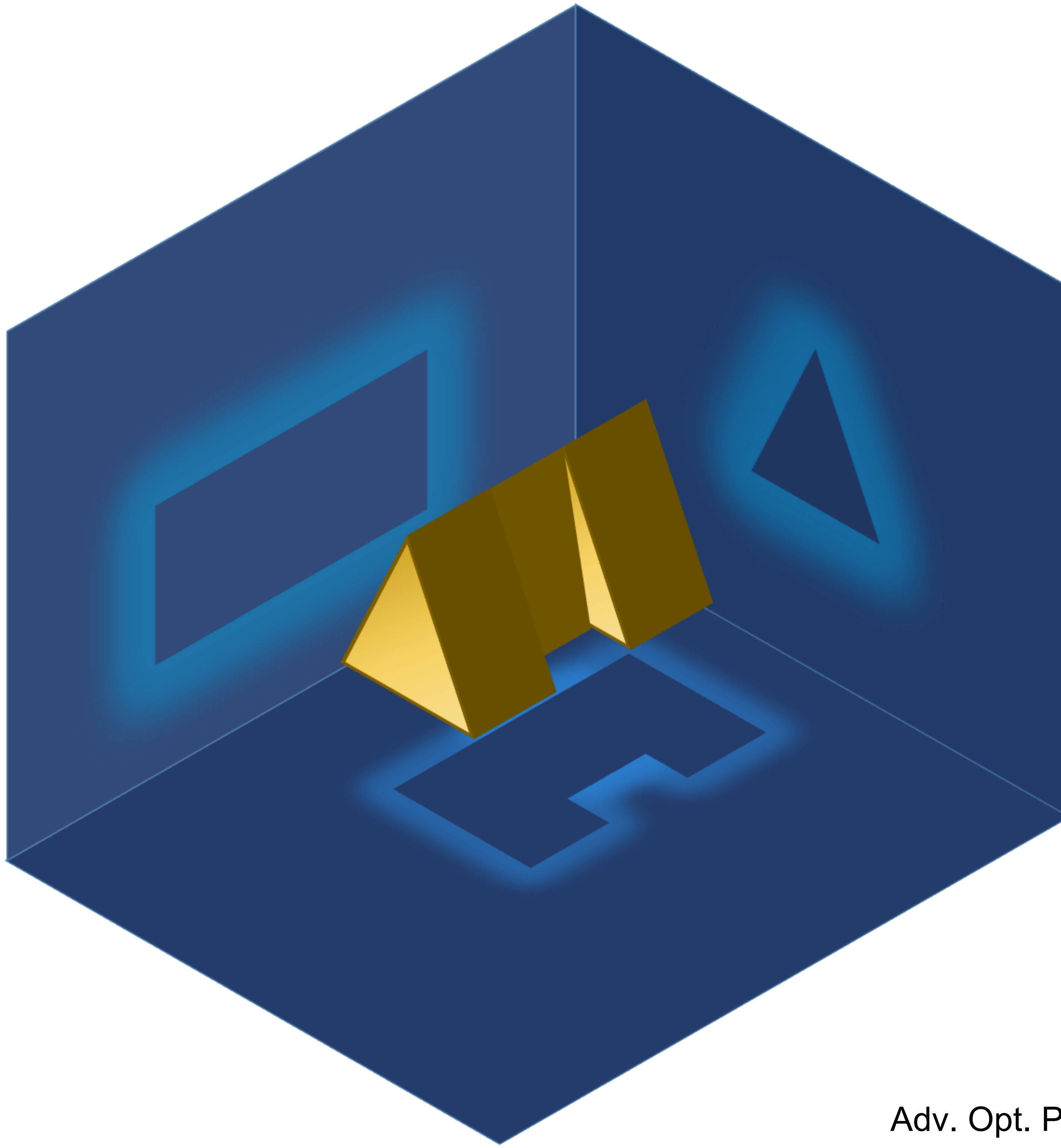


0   1

Purely scalar   Purely vector

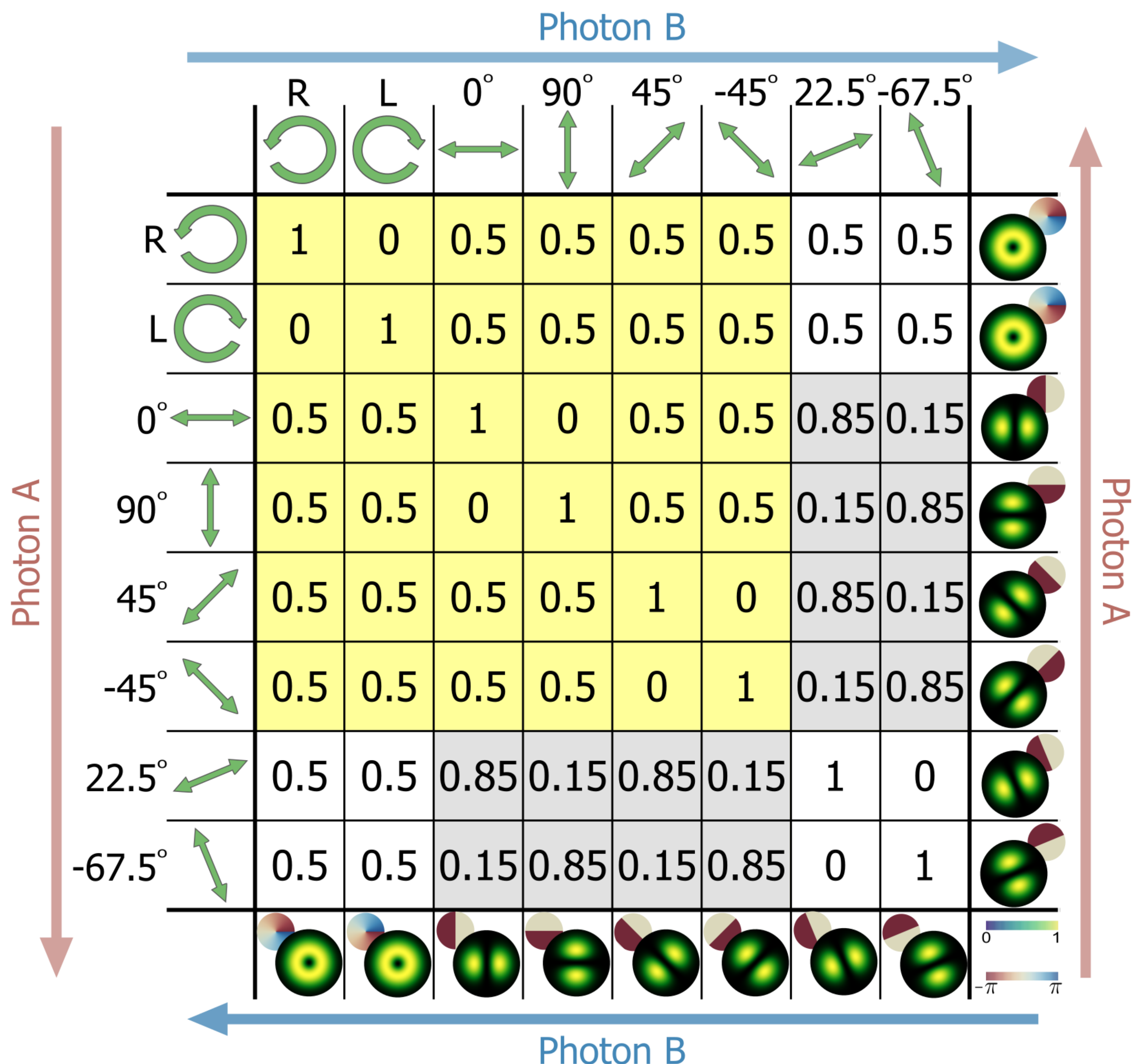
Degree of non-separability

Quantum State Tomography: performing various projections to unravel an unknown state



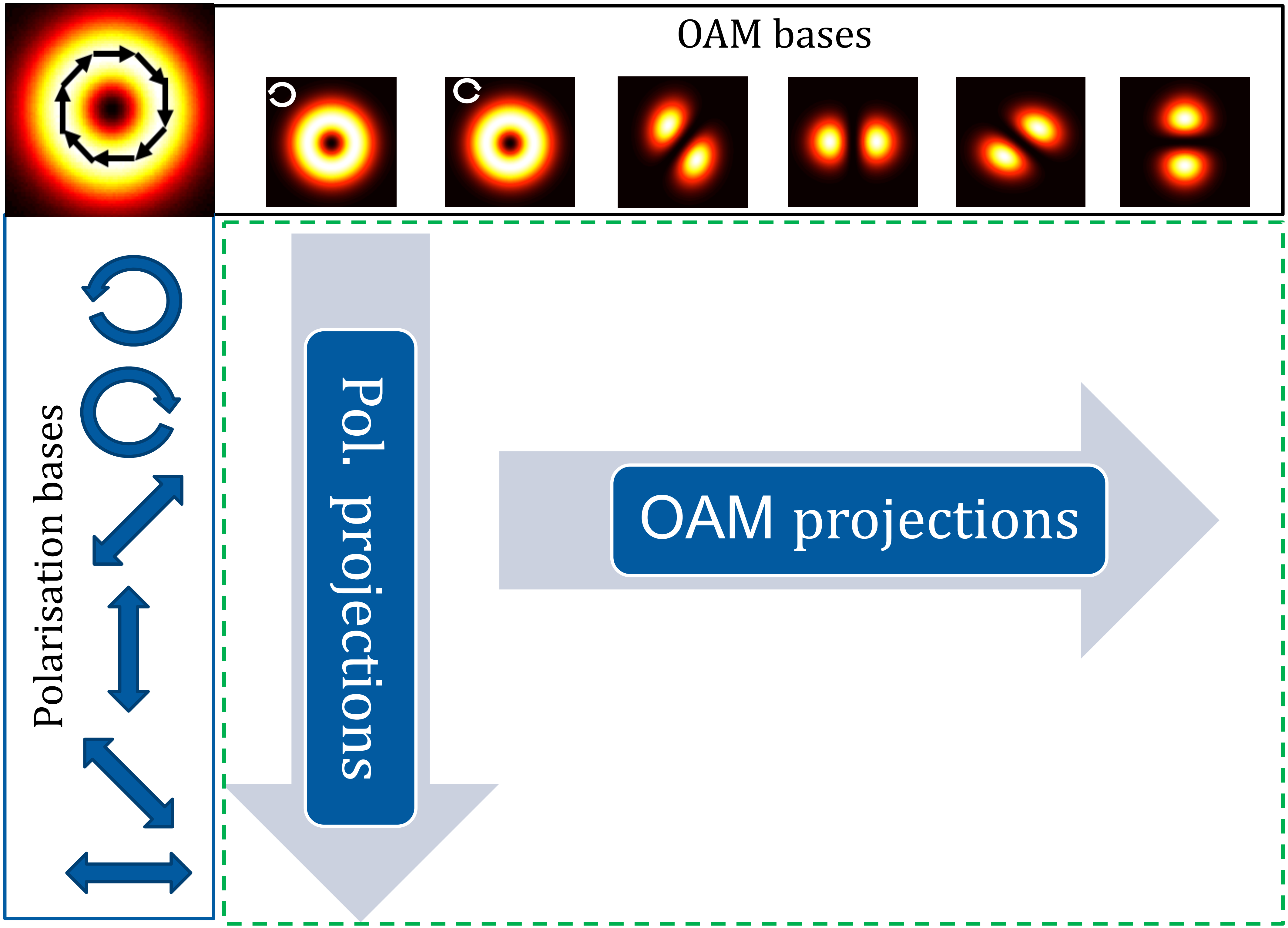
Adv. Opt. Photon. **11**, 67-134 (2019)

Quantum State Tomography: performing various projections to unravel an unknown state

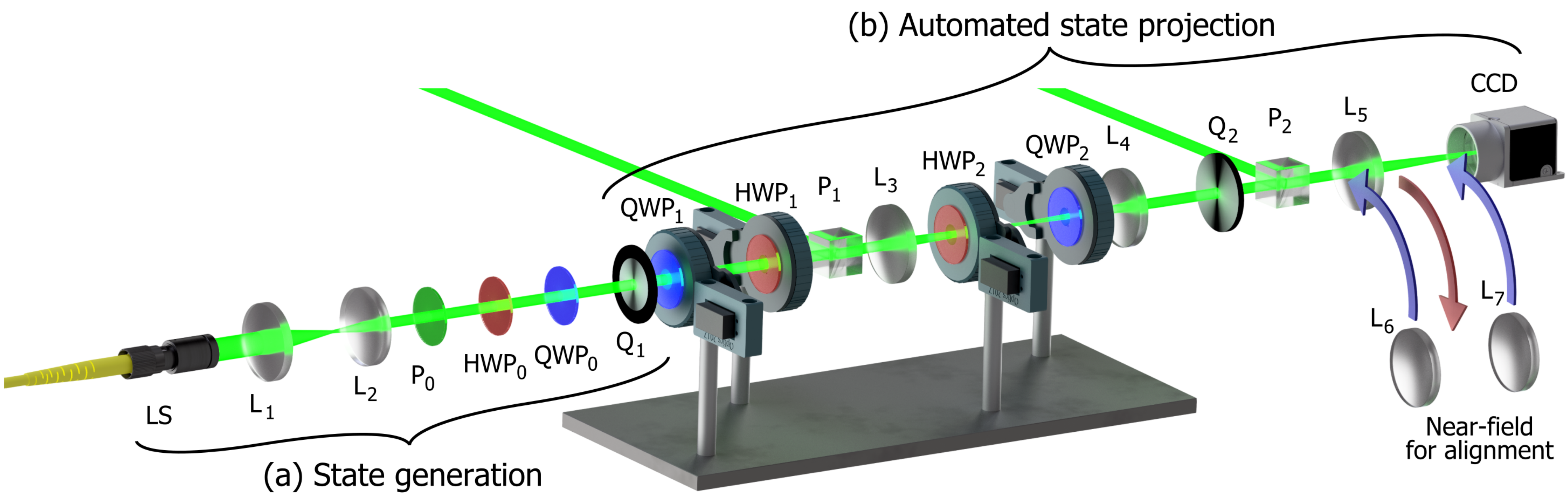


Photon A \ Photon B	R	L	0°	90°	45°	-45°	22.5°	-67.5°
R	1	0	0.5	0.5	0.5	0.5	0.5	0.5
L	0	1	0.5	0.5	0.5	0.5	0.5	0.5
0°	0.5	0.5	1	0	0.5	0.5	0.85	0.15
90°	0.5	0.5	0	1	0.5	0.5	0.15	0.85
45°	0.5	0.5	0.5	0.5	1	0	0.85	0.15
-45°	0.5	0.5	0.5	0.5	0	1	0.15	0.85
22.5°	0.5	0.5	0.85	0.15	0.85	0.15	1	0
-67.5°	0.5	0.5	0.15	0.85	0.15	0.85	0	1

Adv. Opt. Photon. **11**, 67-134 (2019)

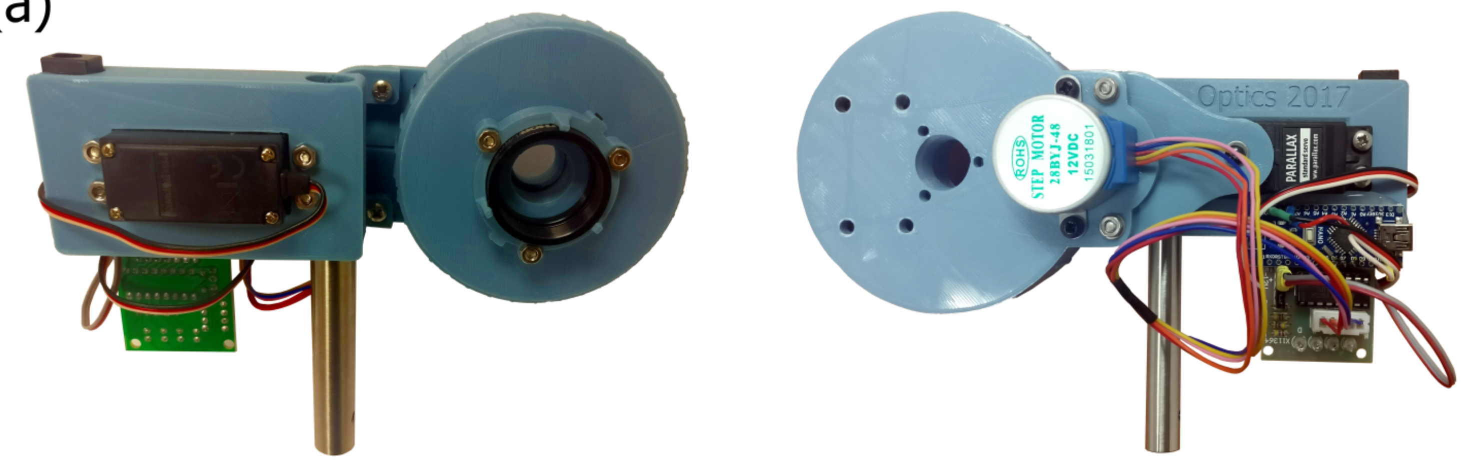

OAM bases
Polarisation bases
Pol. projections
OAM projections

The experiment to implement this is very simple

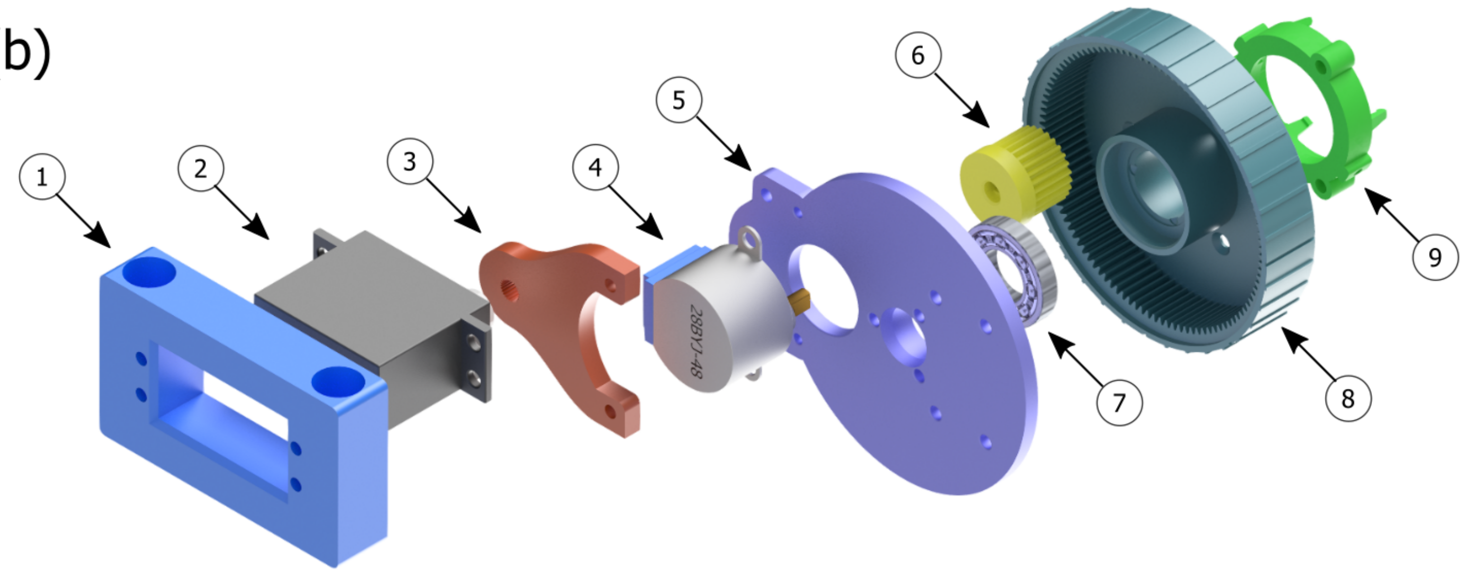


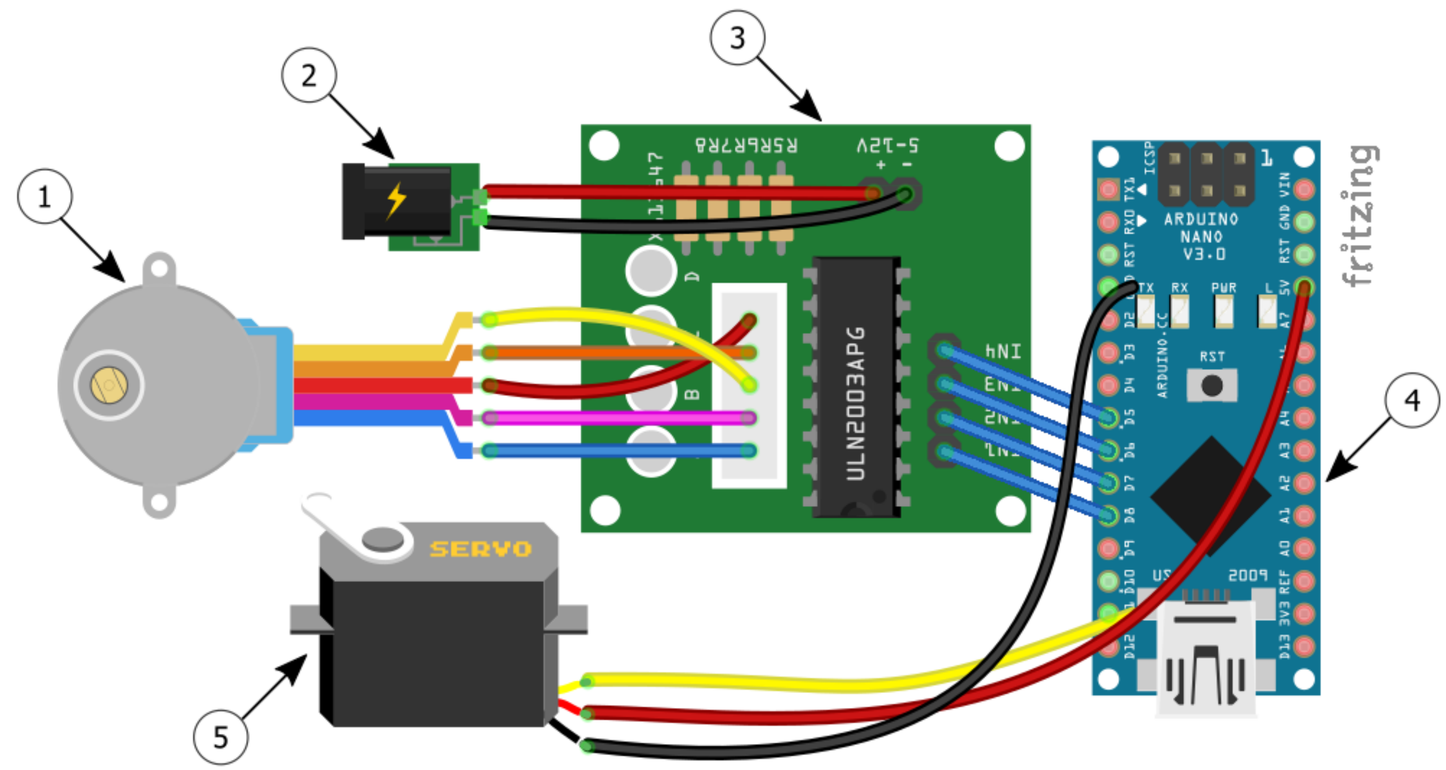
Adv. Opt. Photon. **11**, 67-134 (2019)

(a)

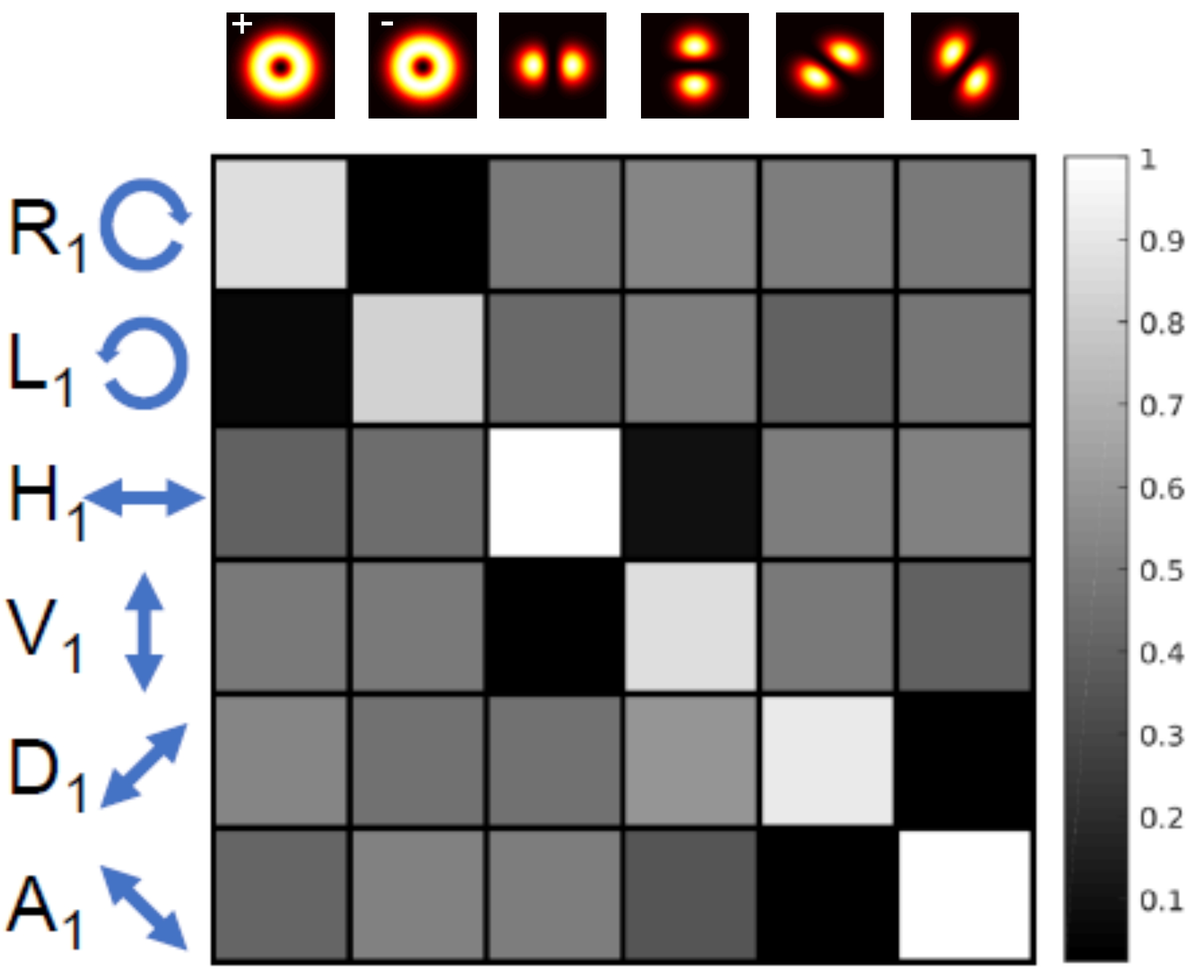

Optics 2017
STEP MOTOR
28BYJ-48
12VDC
PARALLAX

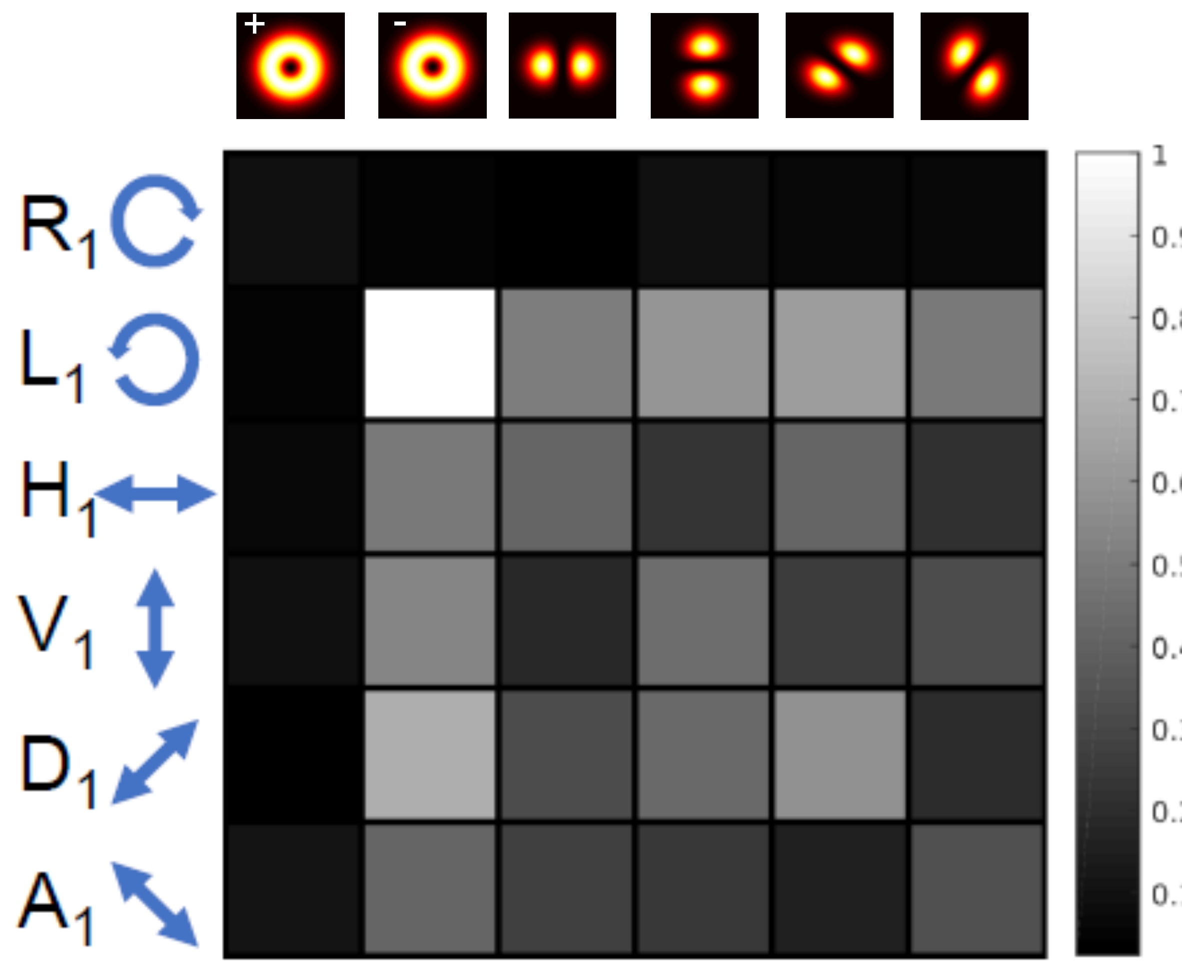
(b)


1
2
3
4
5
6
7
8
9
28BYJ-48


1
2
3
4
5
ULN2003APG
SERVO
ARDUINO
NANO
V3.0
fritzing

The measurement outcome of a QST on classical light



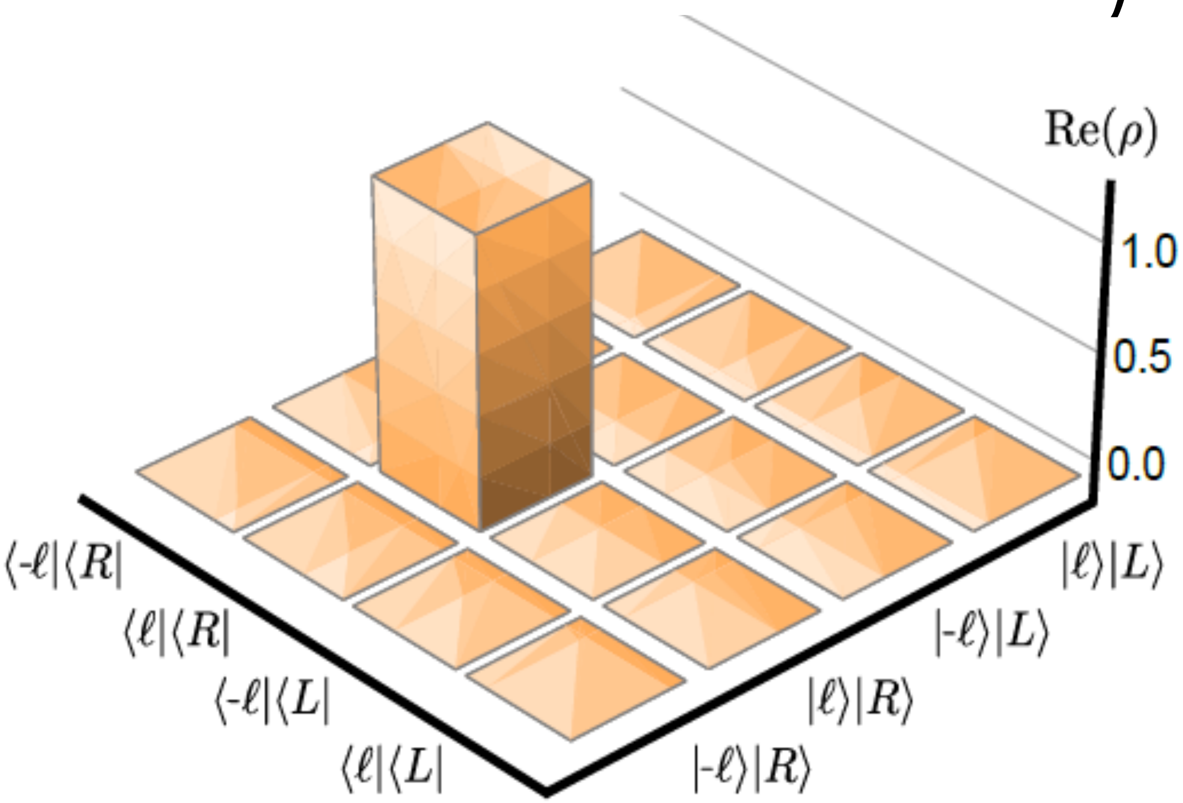


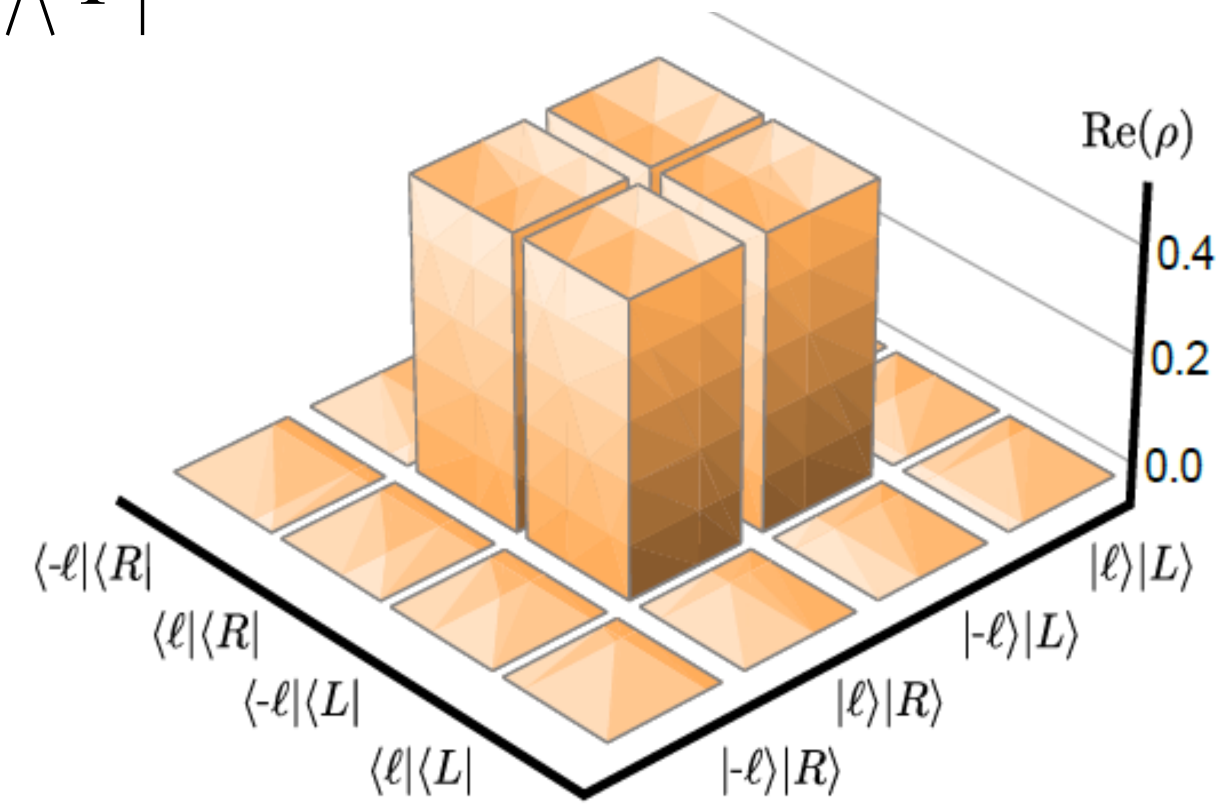
$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left\{|\ell\rangle|R\rangle + |-\ell\rangle|L\rangle\right\}$$

$$|\Psi\rangle = |-\ell\rangle|L\rangle$$

And then show that the classical state looks entangled!

$$\rho = |\Psi\rangle\langle\Psi|$$





$$|\Psi\rangle = |\ell\rangle|R\rangle$$

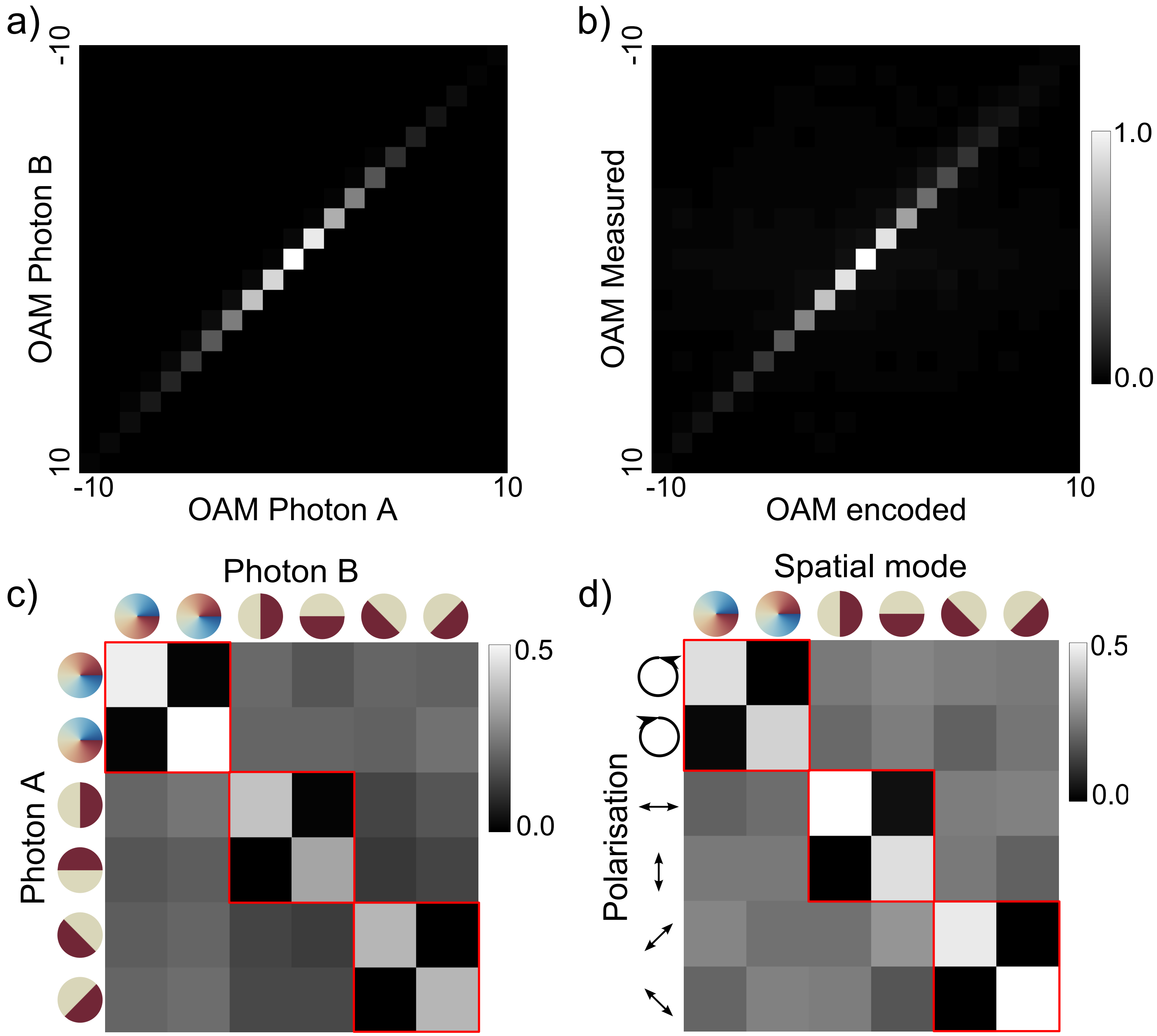
$$|\Psi\rangle = \frac{1}{\sqrt{2}}\left\{|\ell\rangle|R\rangle + |-\ell\rangle|L\rangle\right\}$$

0 → 1

Purely scalar — Purely vector

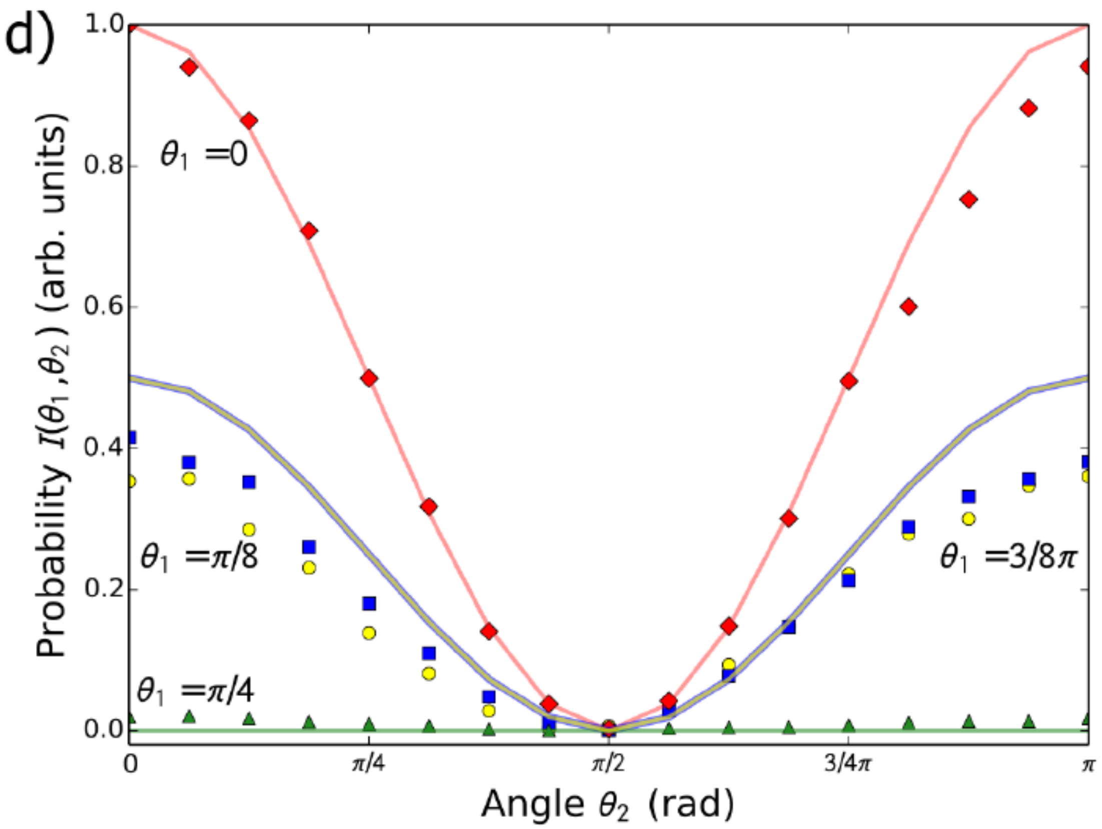
Degree of non-separability

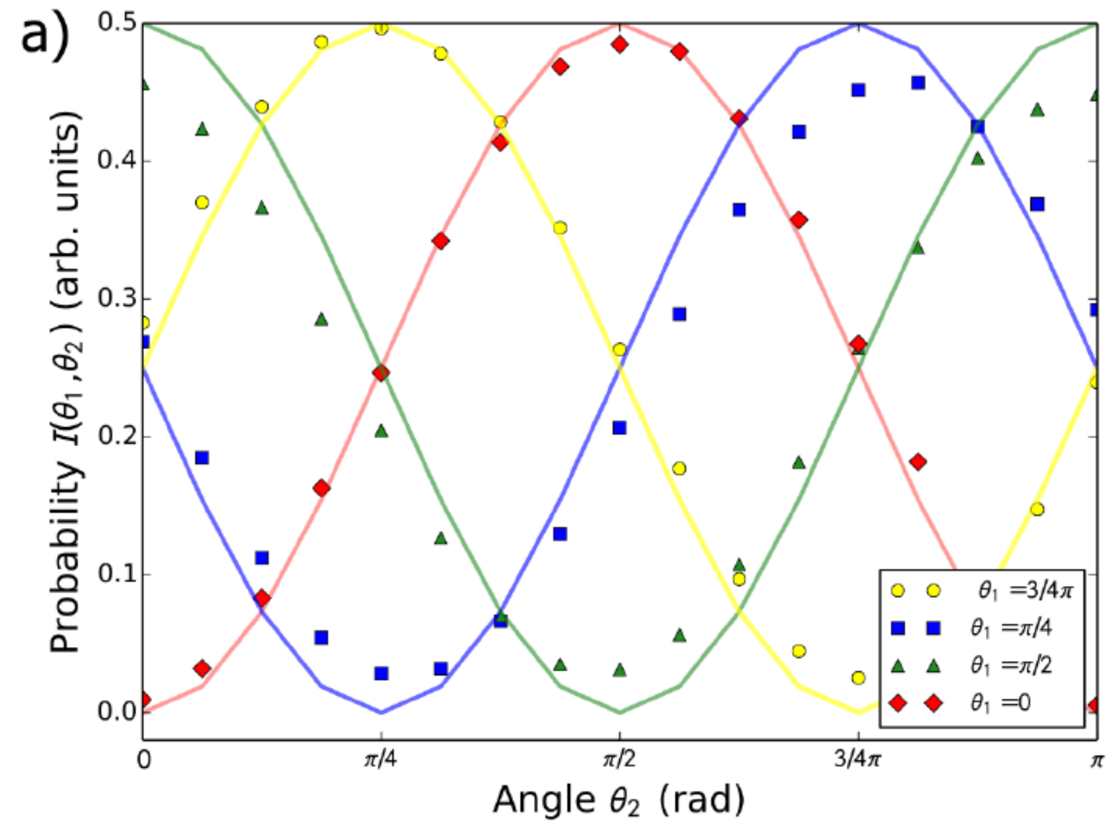
And it works: here is quantum and classical data side by side



Vector beams violate a Bell inequality

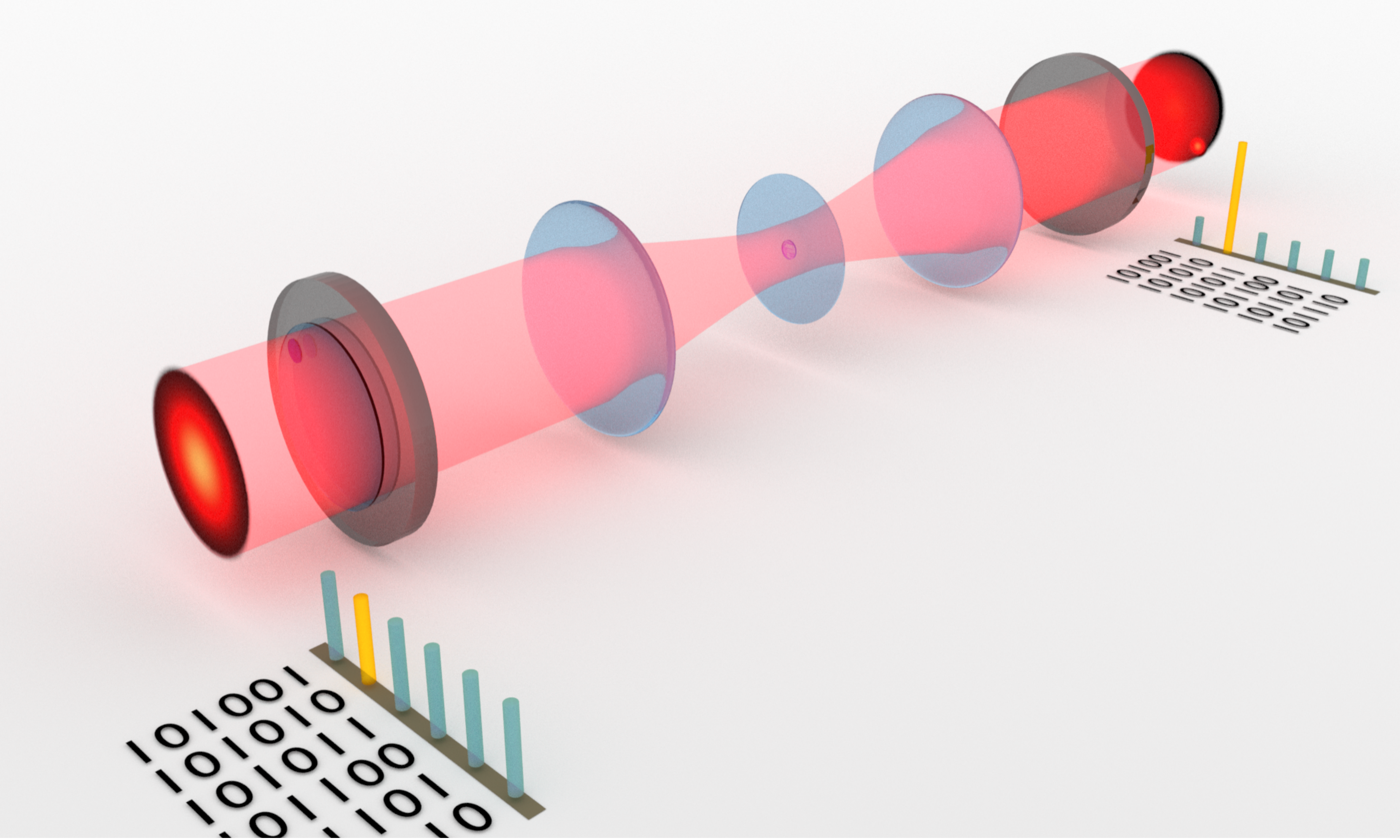
$$S = 2.60 \pm 0.08$$





$$|\Psi\rangle = |-\ell\rangle |L\rangle$$

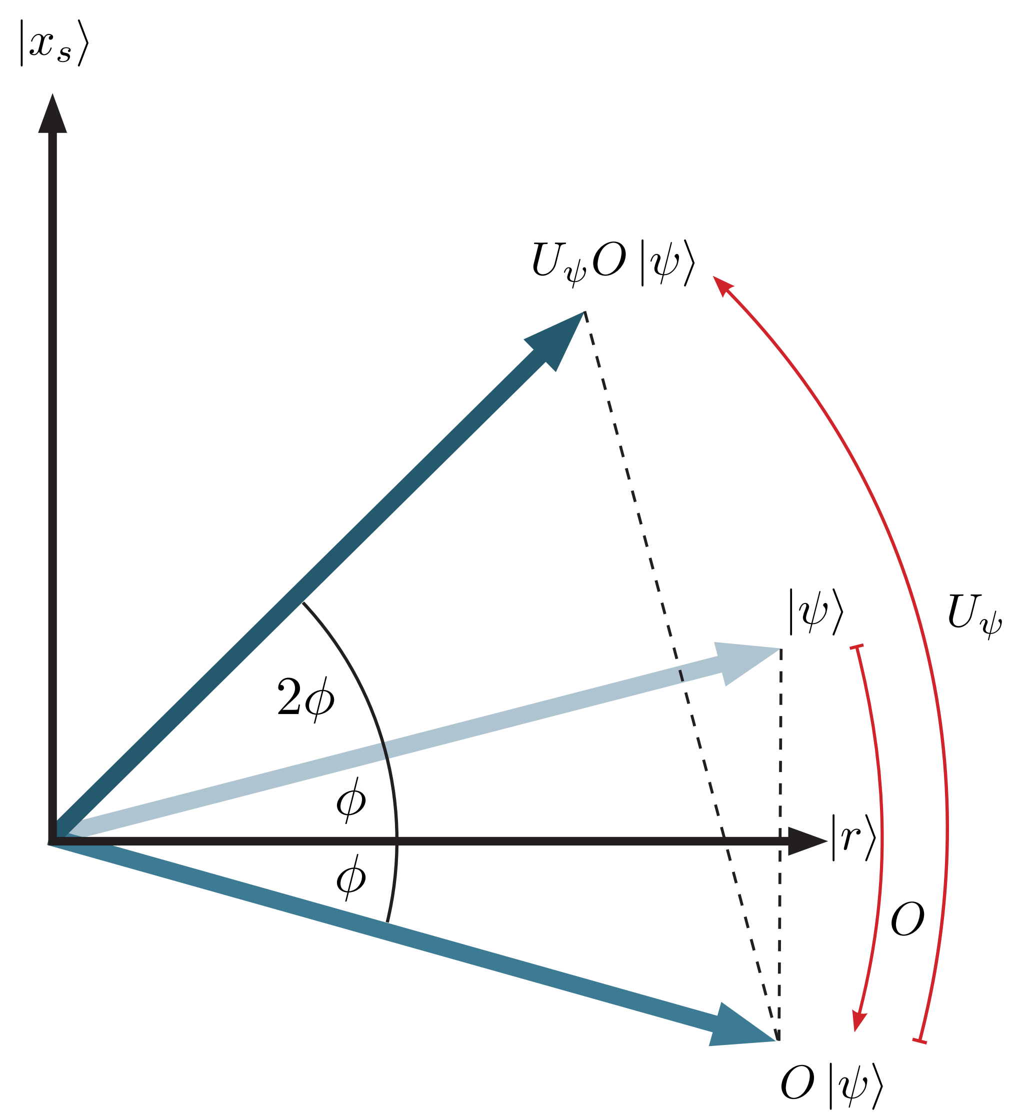
$$|\Psi\rangle = \frac{1}{\sqrt{2}} \left\{ |\ell\rangle |R\rangle + |-\ell\rangle |L\rangle \right\}$$

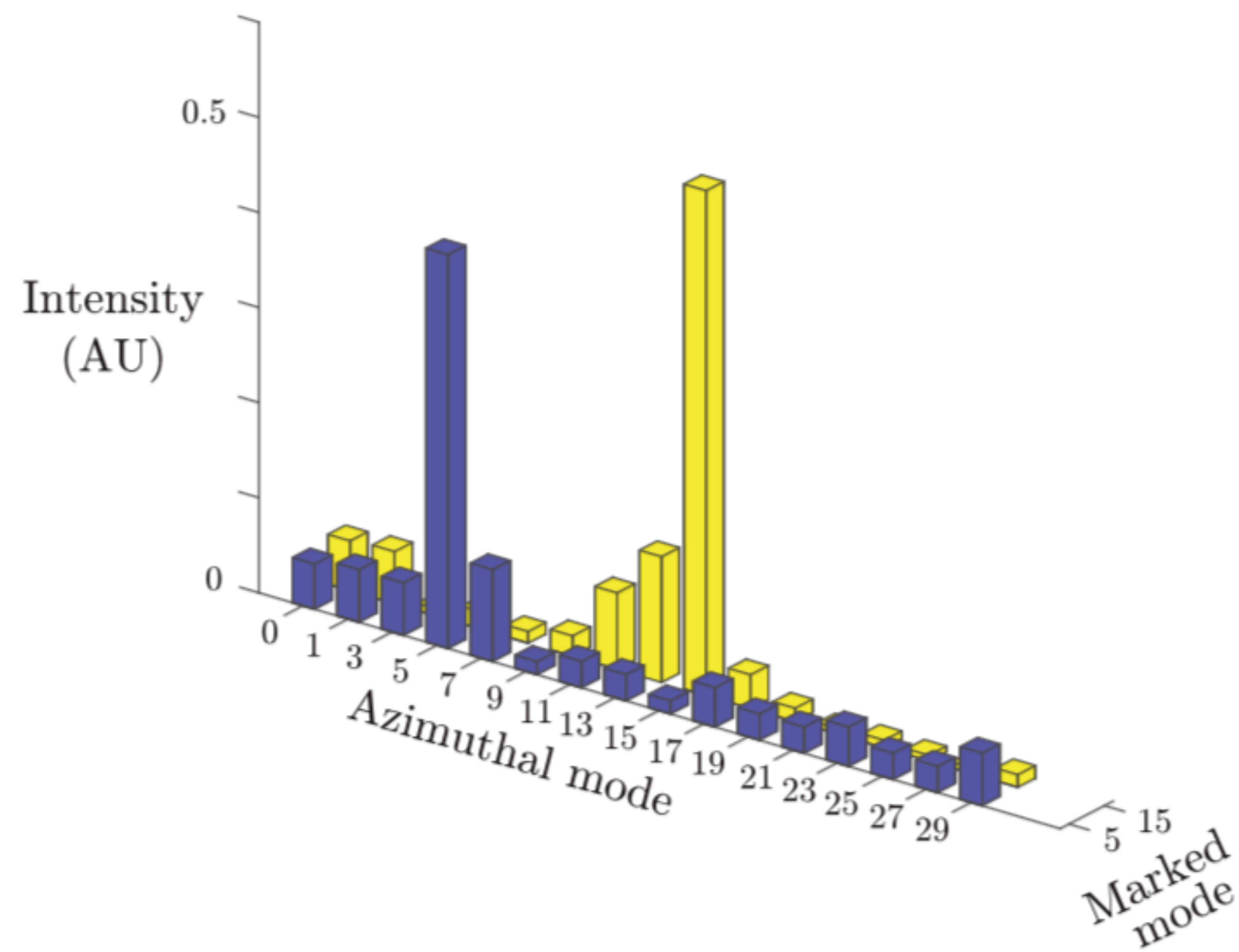


Quantum computing algorithms

With classical light?

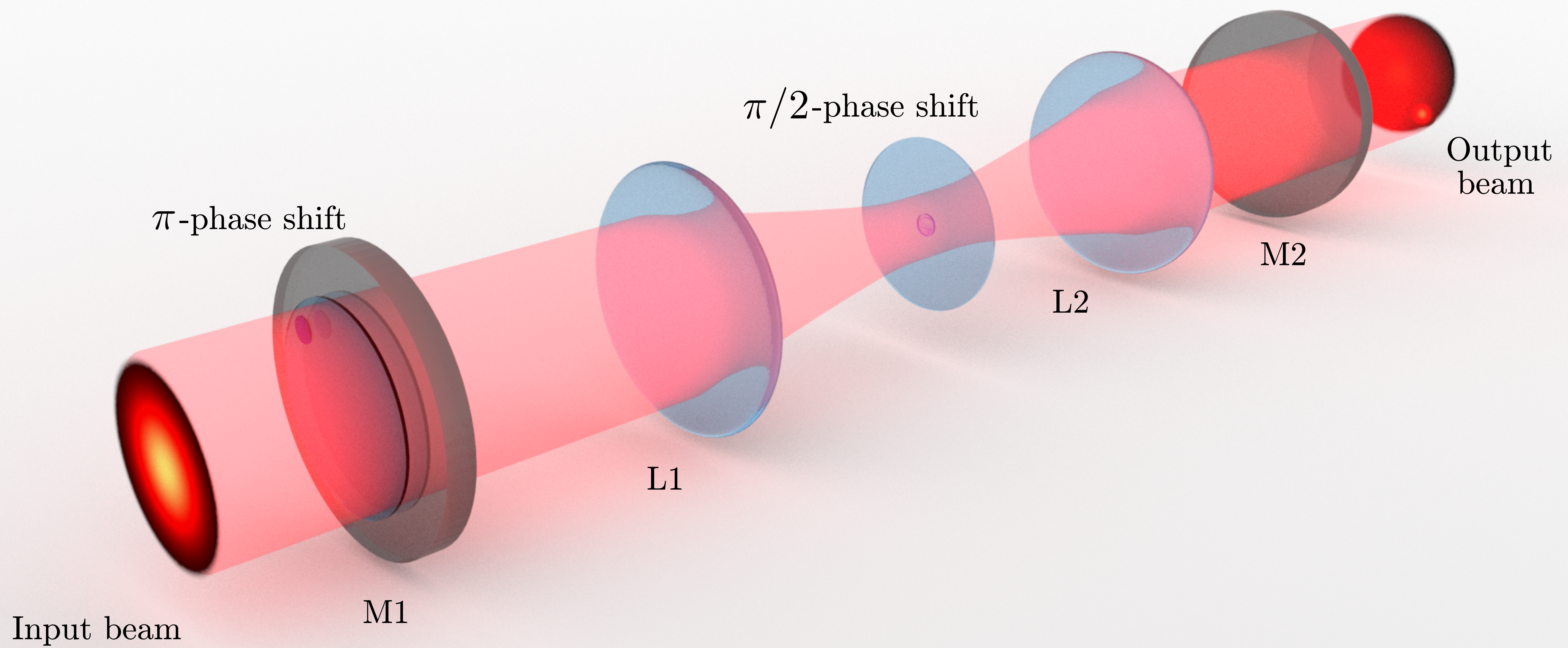
We can use classical light to mimic many quantum processes: the Grover algorithm





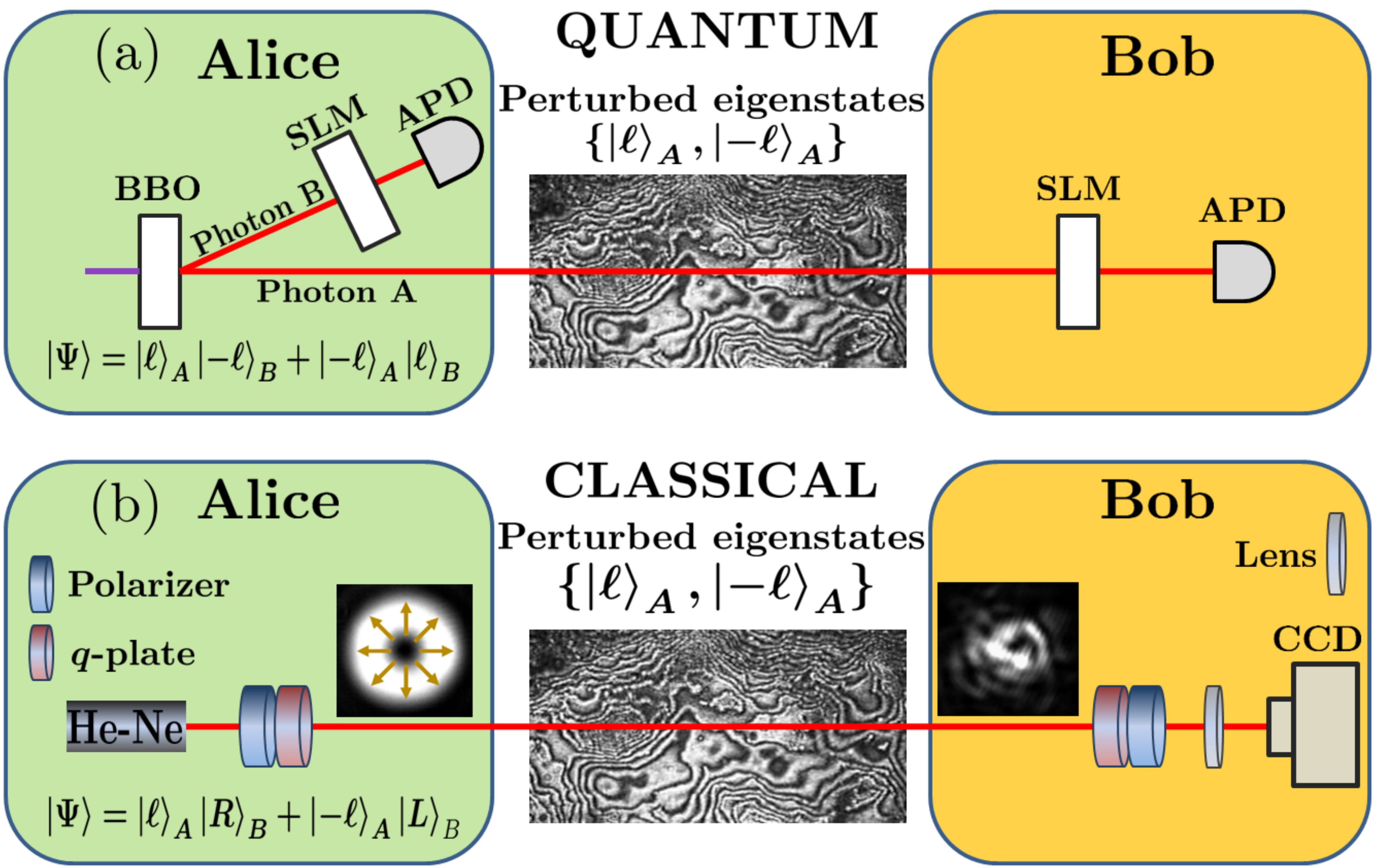
J. Modern Opt. **65**, 1942 (2018)

We can use classical light to mimic many quantum processes: the Grover algorithm

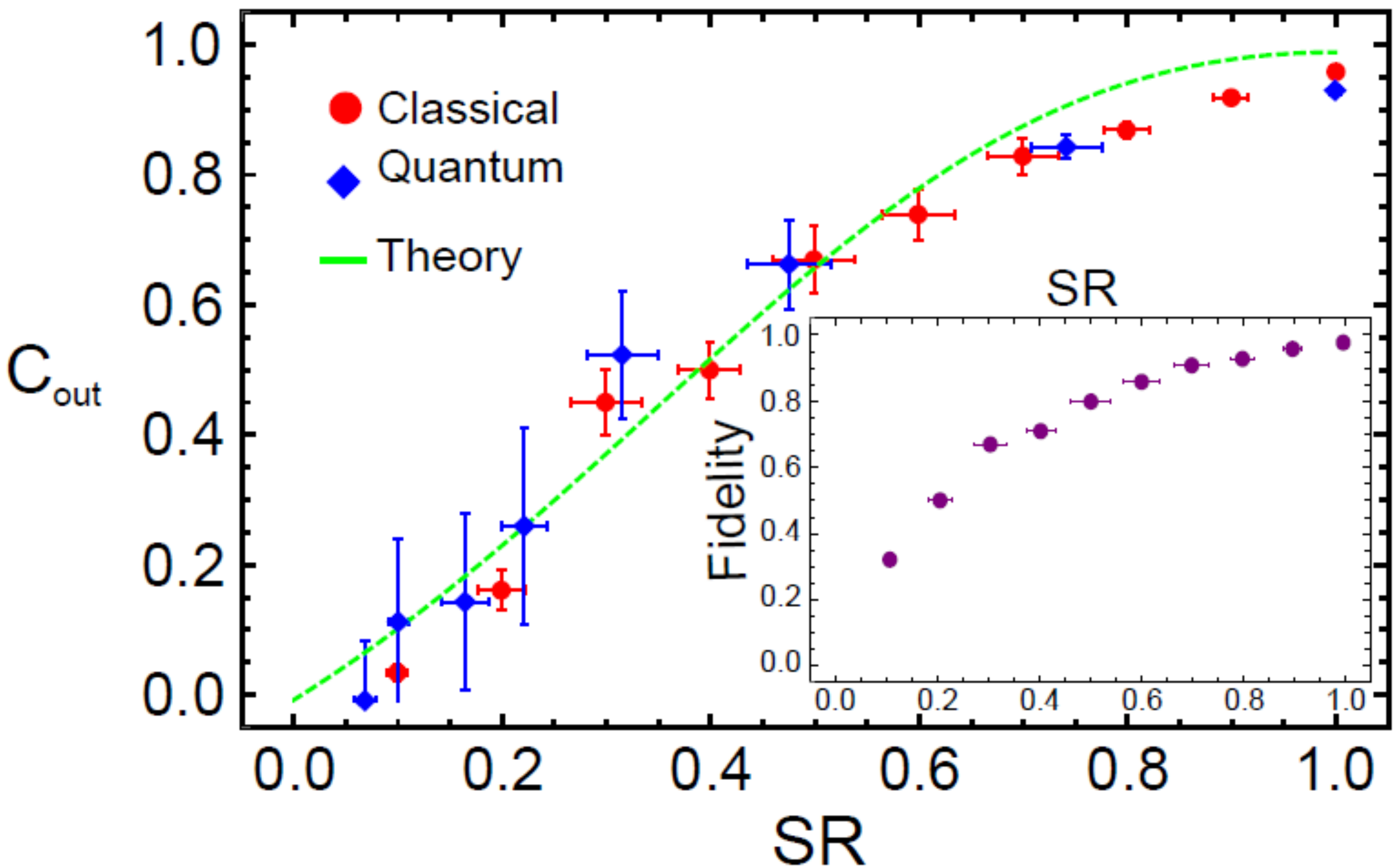


J. Modern Opt. **65**, 1942 (2018)

Blurring the classical-quantum divide with vector states of light

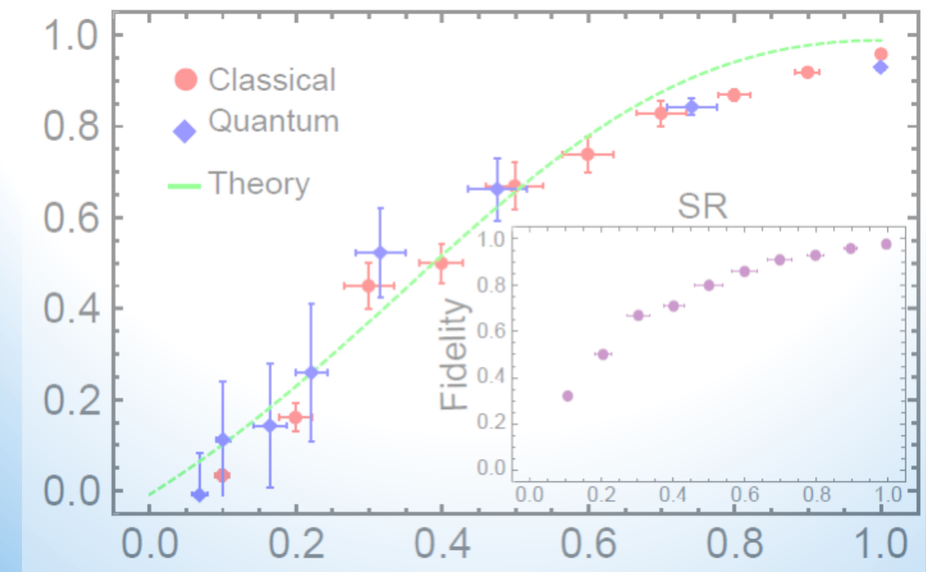


Nature can’t distinguish between the decay of vector vortex beams and the decay of OAM quantum entangled states

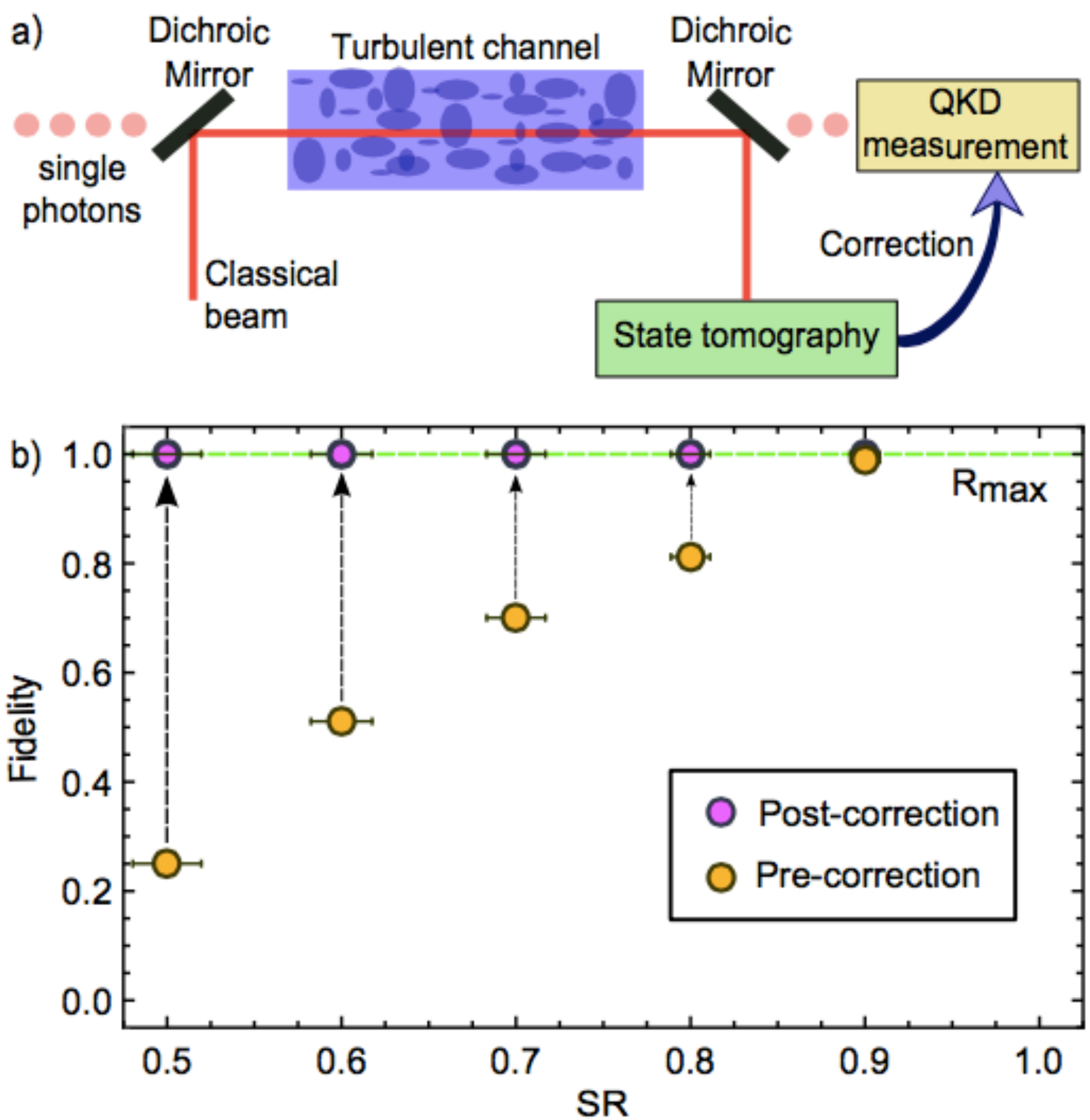


Nature Physics **13**, 397 (2017)

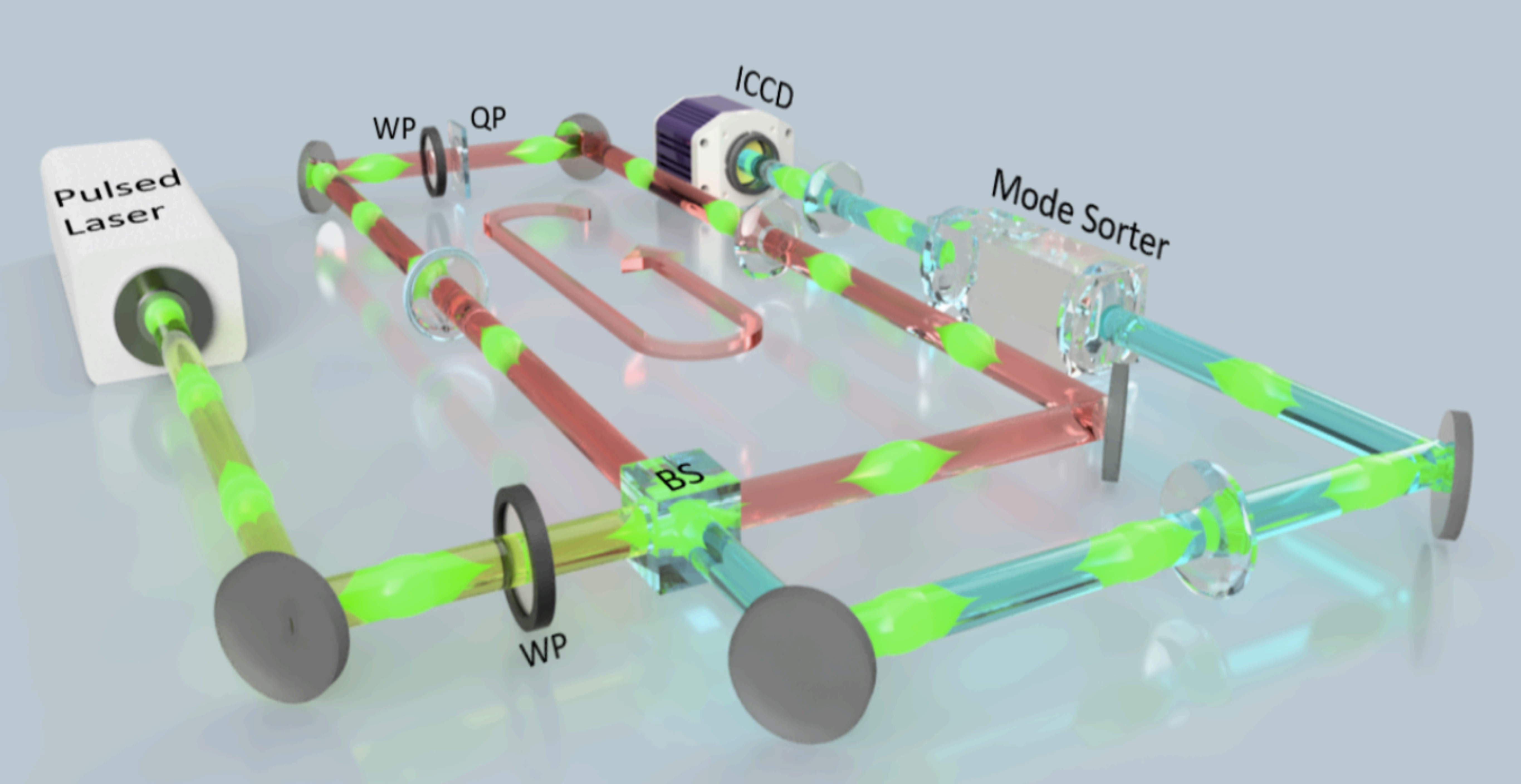
We can convert noise into loss and recover the fidelity of the quantum state



Nature Physics **13**, 397 (2017)



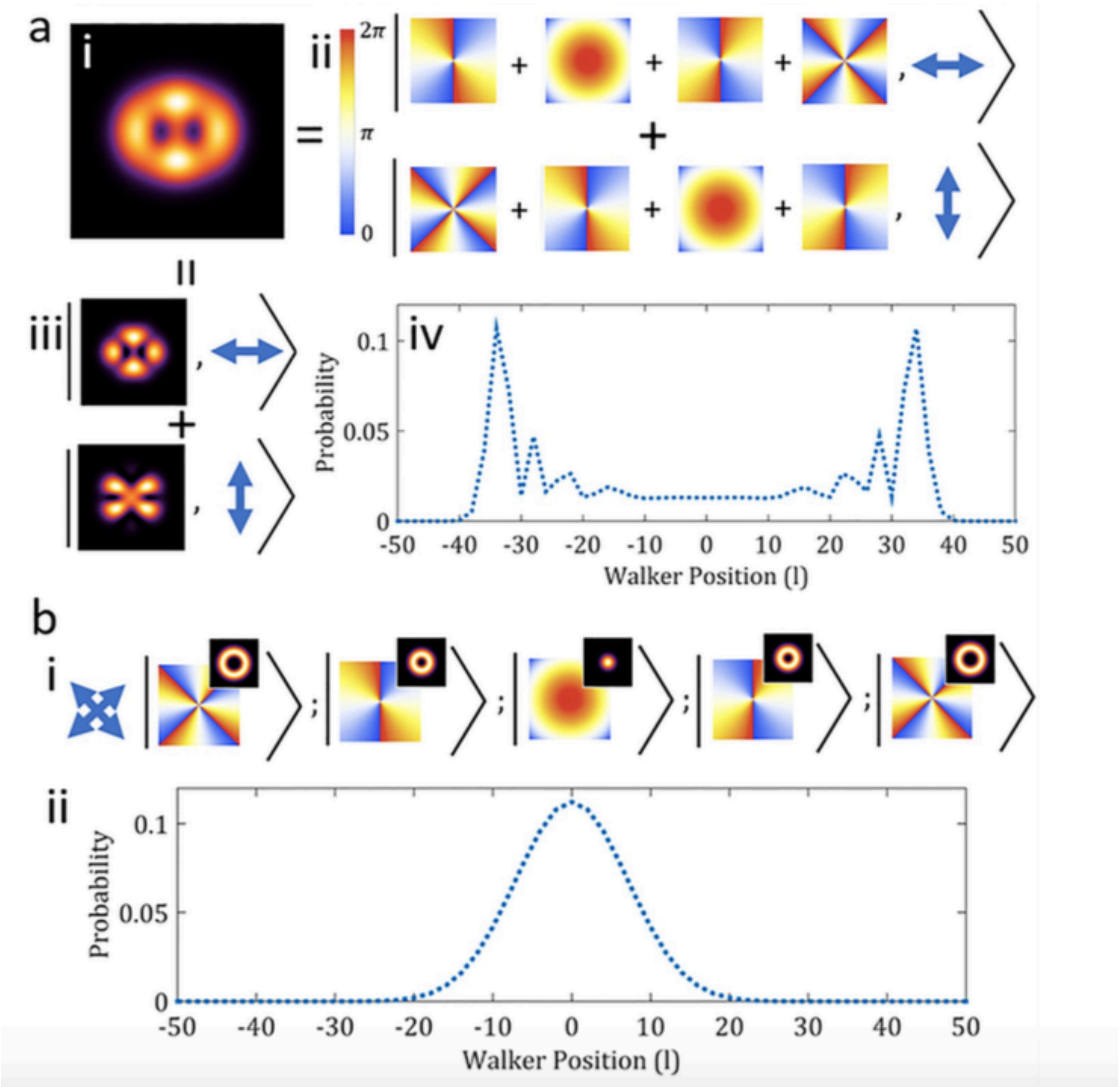
PRA **98**, 062330 (2018)



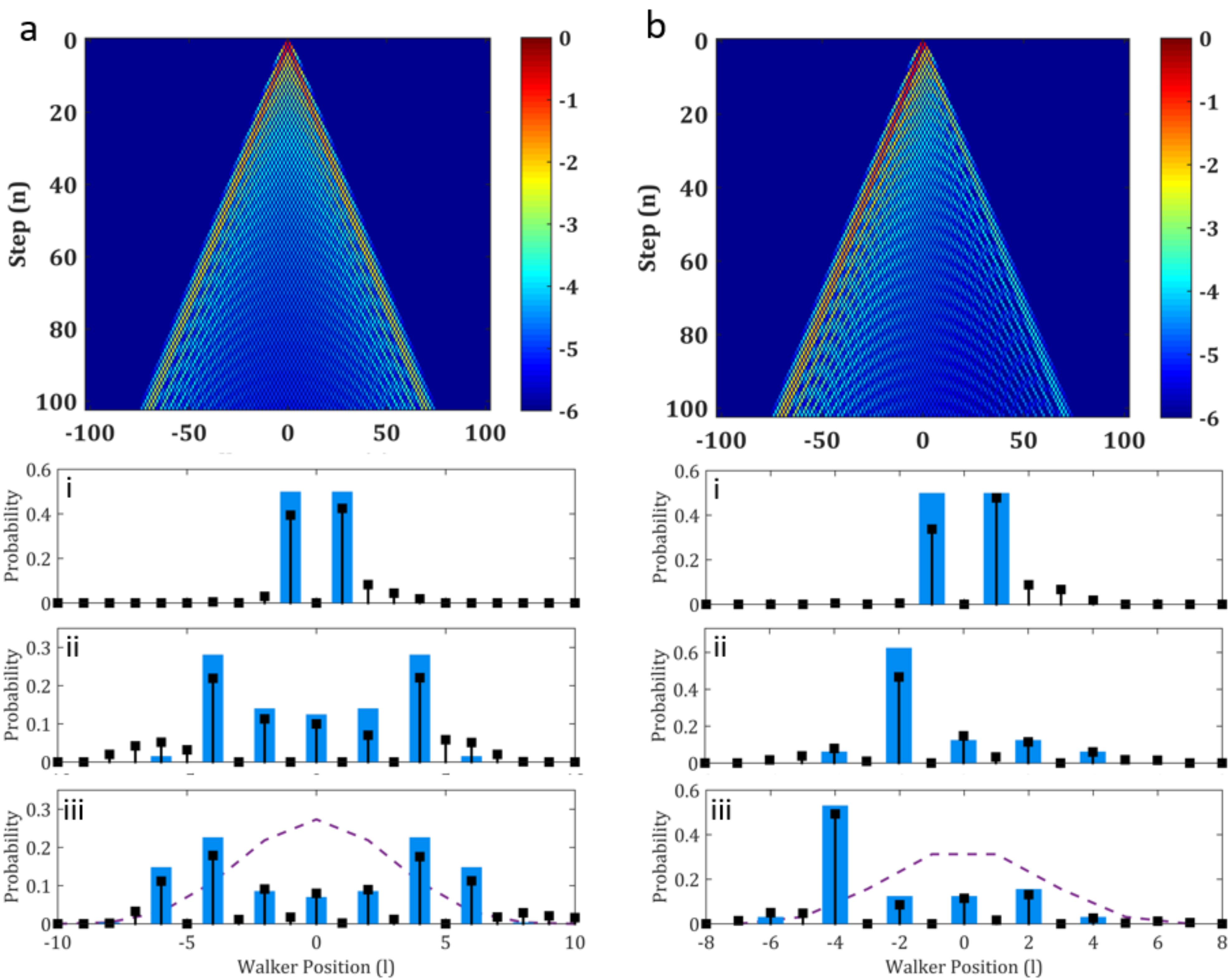
PLoS One **14**(4): e0214891 (2019)

QWs with classical light

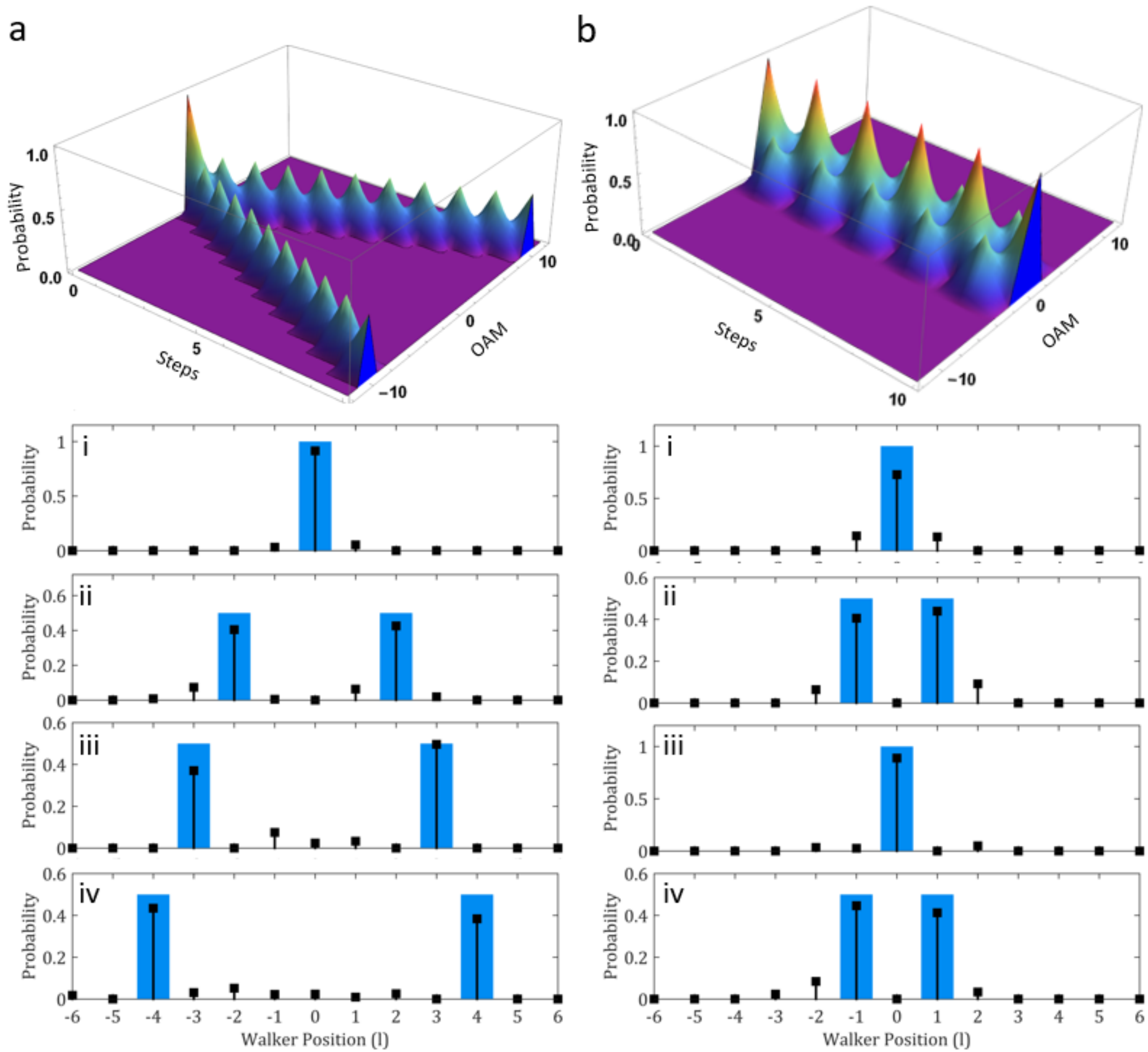
We only need superpositions



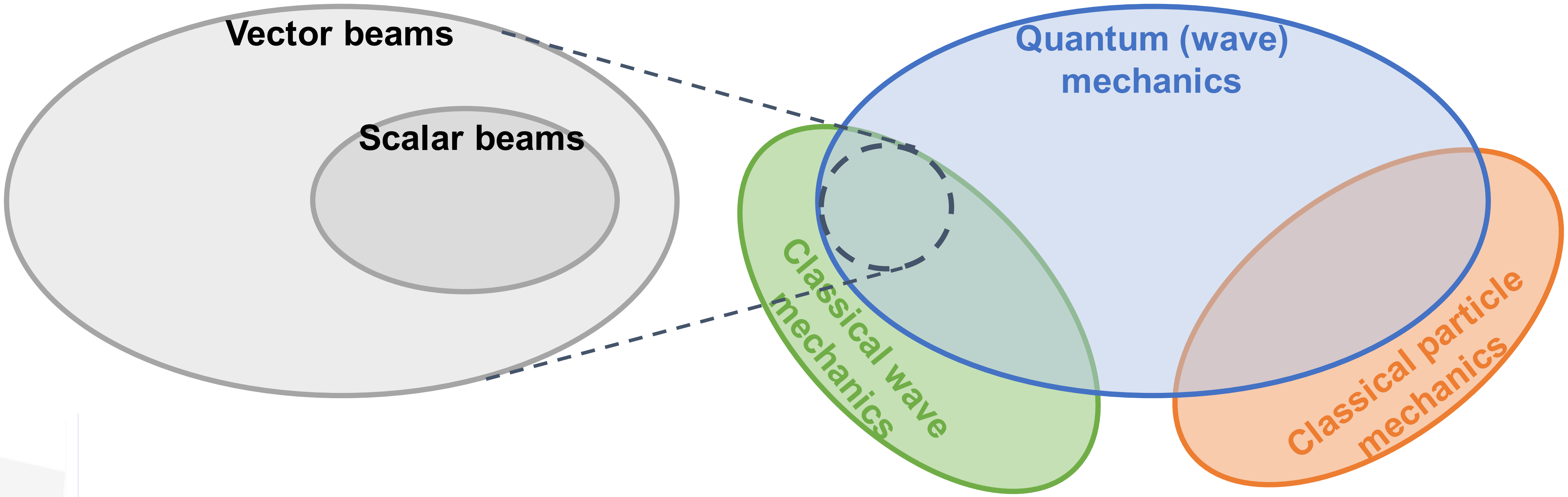
PRL **110**, 263602 (2013)

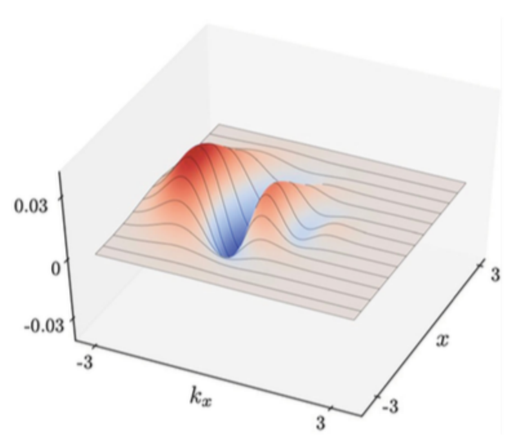


PLoS One **14**(4): e0214891 (2019)



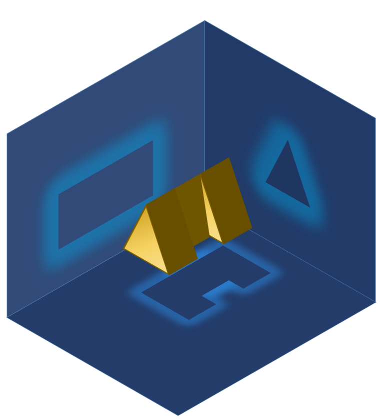
PLoS One **14**(4): e0214891 (2019)





Konrad & Forbes, *Quantum Mechanics and Classical Light*
Contemporary Physics **60**, 1 (2019)

Forbes, Aiello & Ndagano, *Classical Entanglement*
Progress in Optics **64**, 99 (2019)



Toninelli et. al., *Concepts in quantum state tomography and classical implementation with intense light: a tutorial*
Adv. Opt. Photon. **11**, 67 (2019)

Westfälische
Wilhelms-Universität
Münster

ICFO

The Institute
of Photonic
Sciences

HERIOT
WATT
UNIVERSITY

UNIVERSITEIT
STELLENBOSCH
UNIVERSITY

uOttawa

Tecnológico
de Monterrey

华中科技大学
HUAZHONG UNIVERSITY OF SCIENCE AND TECHNOLOGY

HARVARD
UNIVERSITY

VE RI TAS

UNIVERSITY OF
KWAZULU-NATAL

University of
Waterloo

University
of Glasgow

VIA VERITAS VITA

ENSICAEN

Massachusetts
Institute of
Technology

Oregon State
University

nmisa
National Metrology Institute of South Africa

Università
degli Studi
di Padova

Università degli Studi
di Napoli Federico II

OSA The Optical Society

SPIE.

science & technology
Department: Science and Technology
REPUBLIC OF SOUTH AFRICA

technology innovation AGENCY

AIRBUS

NRF

nmisa
National Metrology Institute of South Africa

HOLOEYE

Optelix WIRELESS

CSIR

Thank You

www.structuredlight.org

WITS
UNIVERSITY