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Entanglement-based QKD networking

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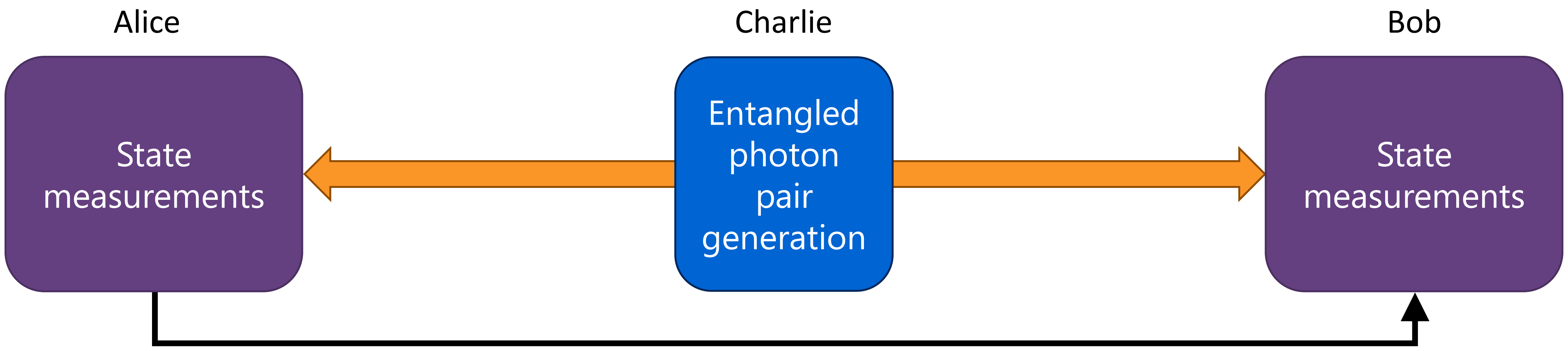
Entanglement-based QKD schemes



QKD protocols test correlations in randomised state measurements (similar to a **Bell test**)

The entangled photon pair source is not required to be trusted

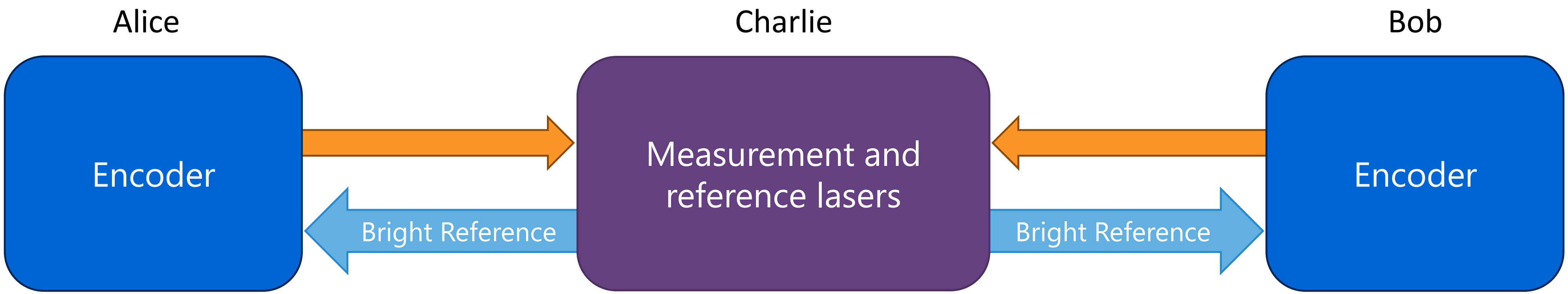
It is sufficient to have entanglement between states at the end-points

Performance can be limited by the quality of the source

Parametric down-conversion can use heralding schemes to limit multiple-pairs

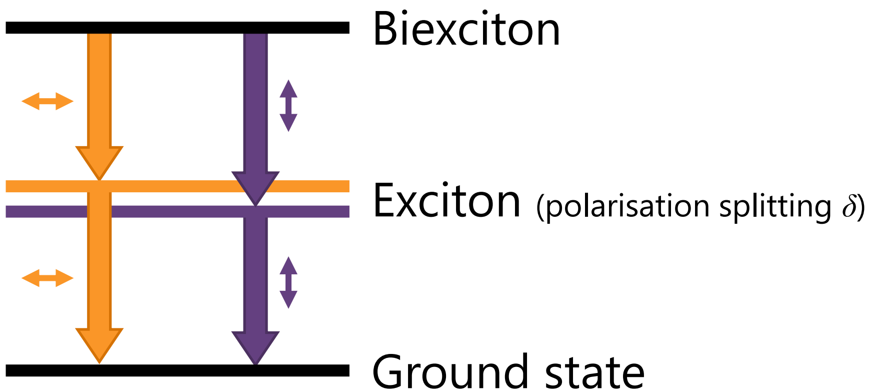
600-km repeater-like quantum communications with dual-band stabilization

M Pittaluga *et al.*, Nature Photonics 15, 530 (2021)

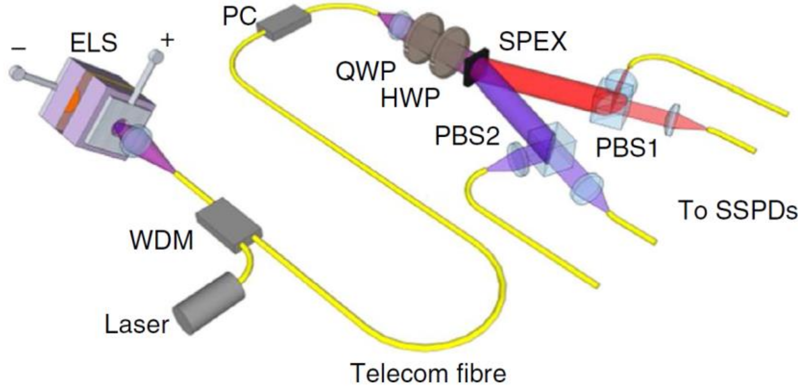


Up to 100s of km no reason to deploy entanglement based

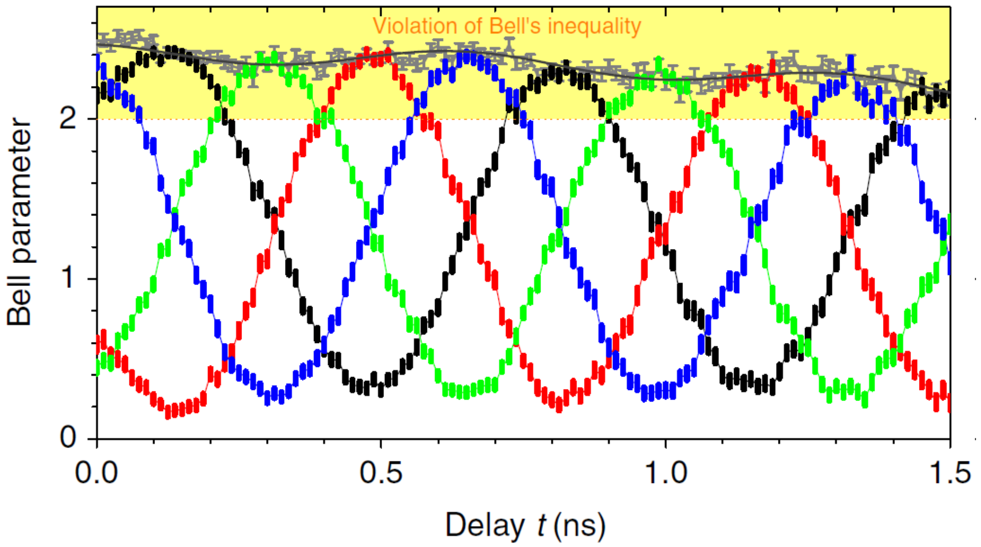
Generating entangled photon pairs from quantum dots



Selection rules result in entanglement of the biexciton and exciton photon polarisations



$$|\Psi_B(t)\rangle = \left[|H_{XX}H_X\rangle + \exp(i\delta t/\hbar)|V_{XX}V_X\rangle\right] / \sqrt{2}$$



M B Ward *et al.*, Nature Commun. 5:3316 (2014)

Optimisations of entangled photon pair sources

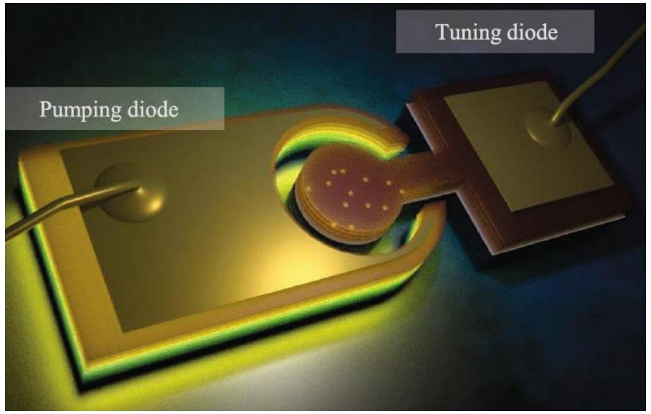
Epitaxial growth improvements:
- more symmetric dots
- wetting-layer-free
- longer coherence times
- *O* Band and *C* Band

J Skiba-Szymanska *et al.*,
Phys. Rev. Appl. 8, 014014 (2017)

Electrically-driven devices

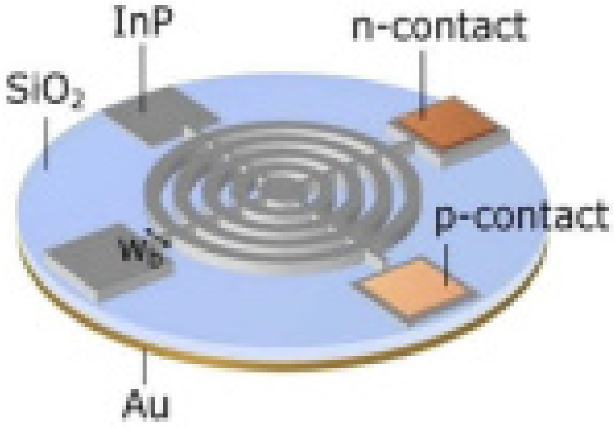
Increased collection efficiency:
- micropillars
- circular Bragg grating

Electrically tuneable with integrated optical pump diode



Z-H Xiang *et al.*,
Commun. Phys. 3:121 (2020)

Electrically driven with circular Bragg grating



A Barbiero *et al.* Opt. Express 30, 10919 (2022)

Transferring entanglement over optical fibre

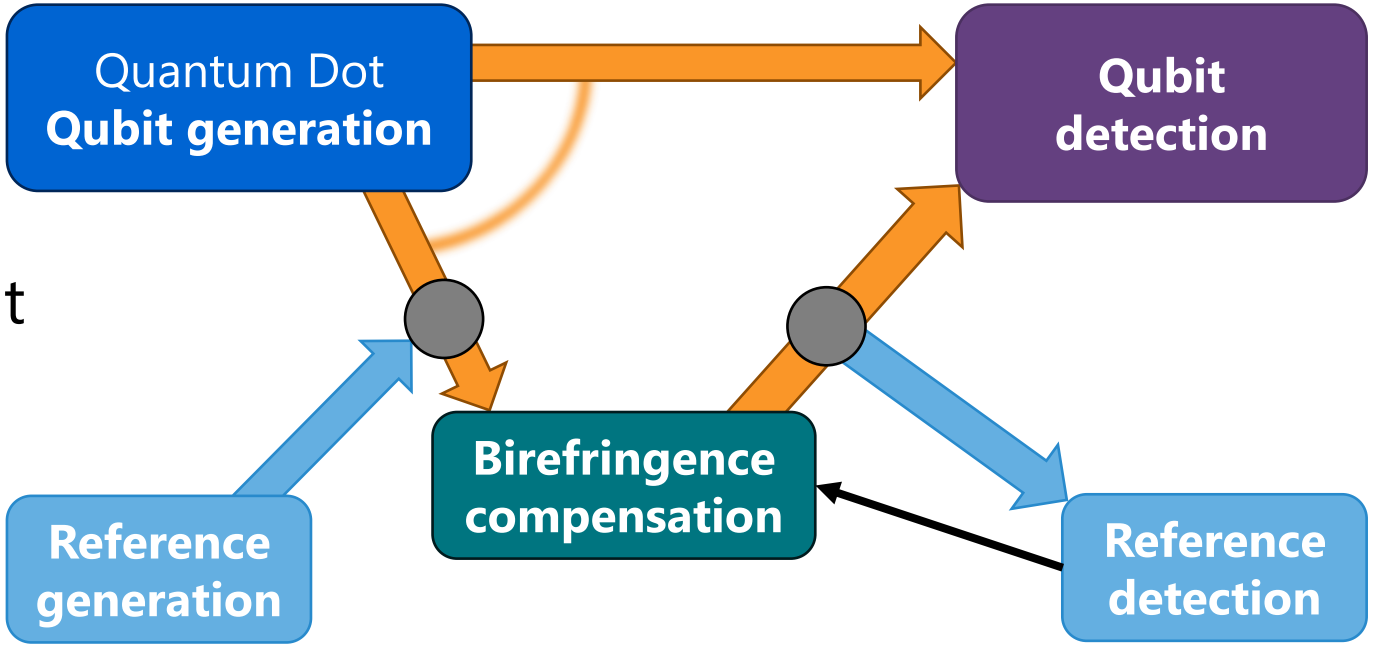
Can we distribute polarisation entangled states?

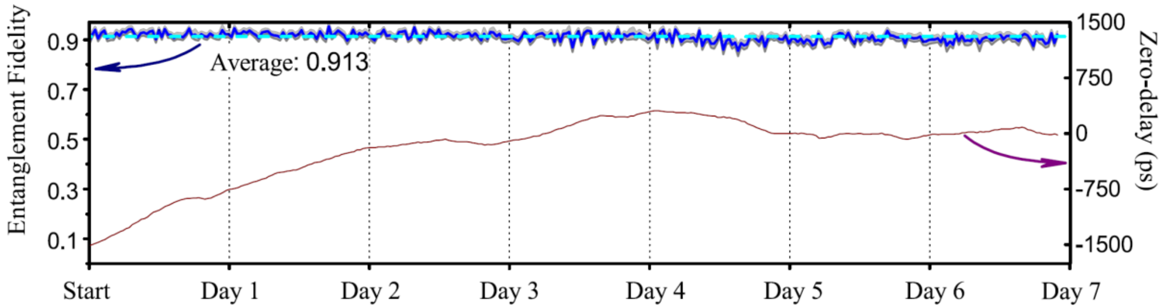
Need to monitor fibre and implement birefringence stabilisation system

Essentially ellipsometry

Practical in deployed fibre, e.g. monitoring multiple polarisations

Time bin entanglement can be easier to distribute – can transform between the two





X-H Xiang *et al.*, Sci. Rep. 9:4111 (2019)

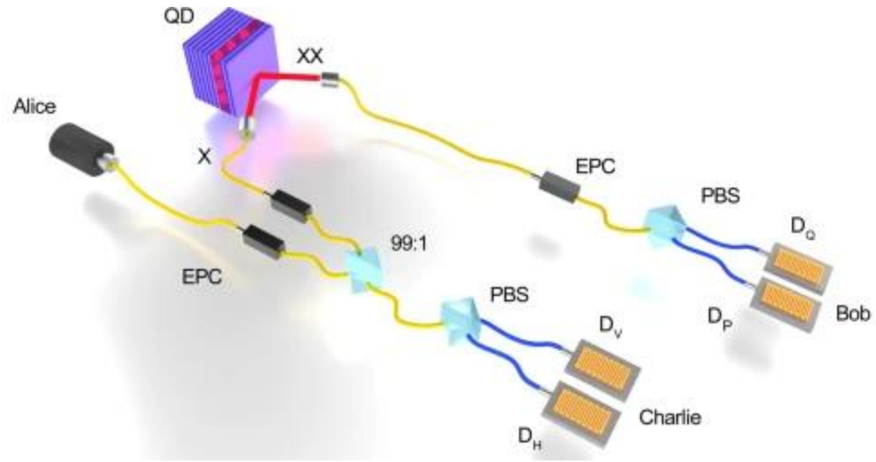
Teleportation

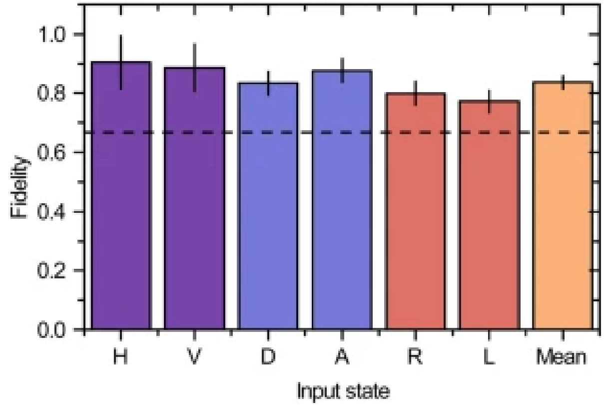
For longer distances can teleport

Laser states teleported using entangled photon pairs from quantum dot

To avoid success probability falling cannot keep repeating without quantum memory

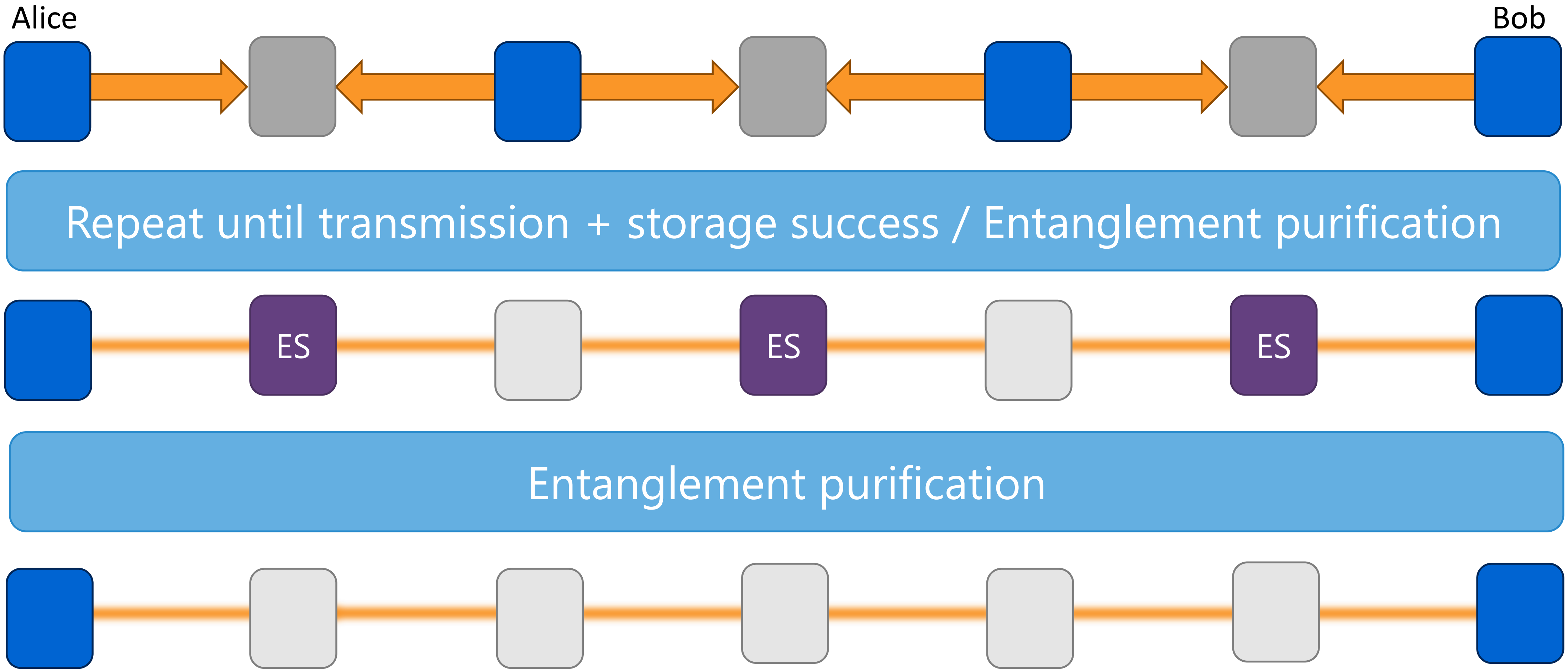
Quantum teleportation using highly coherent emission from telecom C-band quantum dots





M Anderson *et al.*, npj Quantum Information 6, 14 (2020)

Quantum repeater



For long chains, high success probability and fidelity can be complicated

Larger multi-photon states – Multipartite entanglement

Entanglement of multiple photons can be more robust against dissipation than single entangled photon pairs

Ultimately this can relax the requirement for quantum memory

Complexity remains in creating the states and also in measuring them etc.

Protocol success can be probabilistic

Examples:

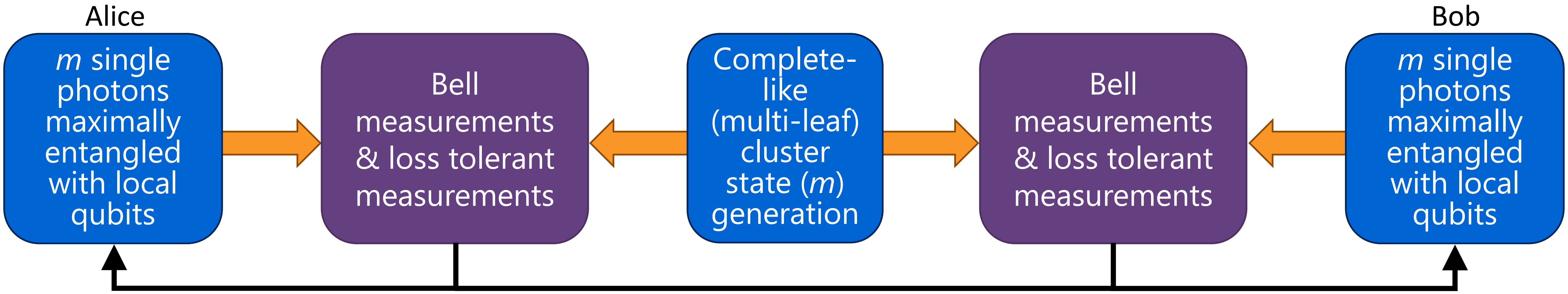
$$|\mathrm{W}\rangle = \frac{1}{\sqrt{3}}(|001\rangle + |010\rangle + |100\rangle)$$

$$|\mathrm{GHZ}\rangle = \frac{|000\rangle + |111\rangle}{\sqrt{2}}$$

(Greenberger–Horne–Zeilinger states)

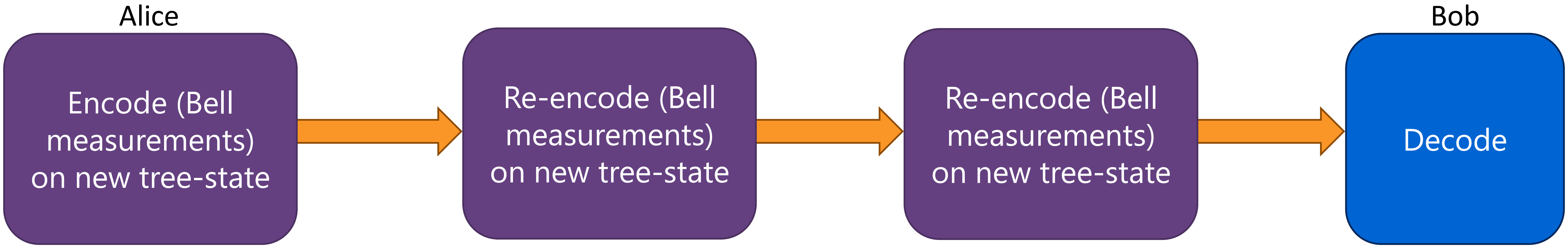
Multipartite entanglement quantum repeaters

All-photonic quantum repeaters



K Azuma, K Tamaki and H-K Lo, Nature Commun. 6:6787 (2015)

One-Way Quantum Repeater



J Borregaard *et al.*, Phys. Rev. X 10, 021071 (2020)

Multipartite entanglement – creation by a quantum emitter

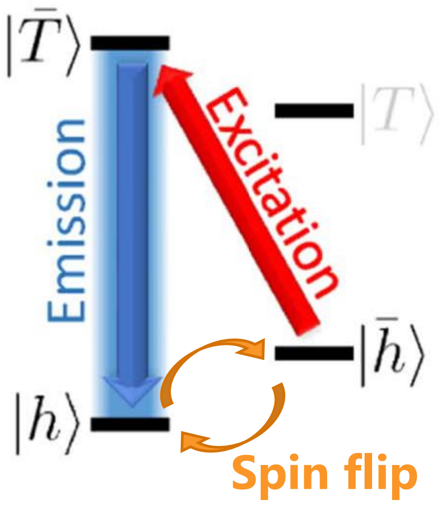
Initialise a charged quantum dot

Resonantly drive transition to generate a photon conditional on the spin state

Manipulate the hole spin using laser pulses

Offers deterministic creation of time-bin entangled multi-photon states

Protocol variations can generate W-states, GHZ-states and linear cluster states



N H Lindner and T Rudolph, Phys. Rev. Lett. 103 ,113602 (2009)
I Schwartz *et al.*, Science 354, 434–7 (2016)
J P Lee *et al.*, Quantum Sci. Technol. 3, 024008 (2018)
J P Lee *et al.*, Quantum Sci. Technol. 4, 025011 (2019)

Multiple approaches to quantum repeaters

Teleportation schemes

Highly dependent upon what quantum memory becomes available and when

Roll out of dedicated chains repeater nodes / Application on more general quantum internet

Distributed quantum computer maintaining remote entanglement resources with error correction

Multipartite entanglement schemes

States can be generated using a quantum emitter e.g. quantum dot

Range of photonic repeater schemes: including one-way repeater

Lower (incl. no) requirements for quantum memory: including all-photonic

Continuous-Variable schemes

Multiple approaches to quantum repeaters

Various factors could impact protocol choice at different stages of development

Success probability	**Fidelity / error correction schemes**
Distance, latency requirement etc.	**Component availability** (incl. quantum memory)

Networks can expect to need to adapt to new protocols

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