Distributing Entanglement with Separable States

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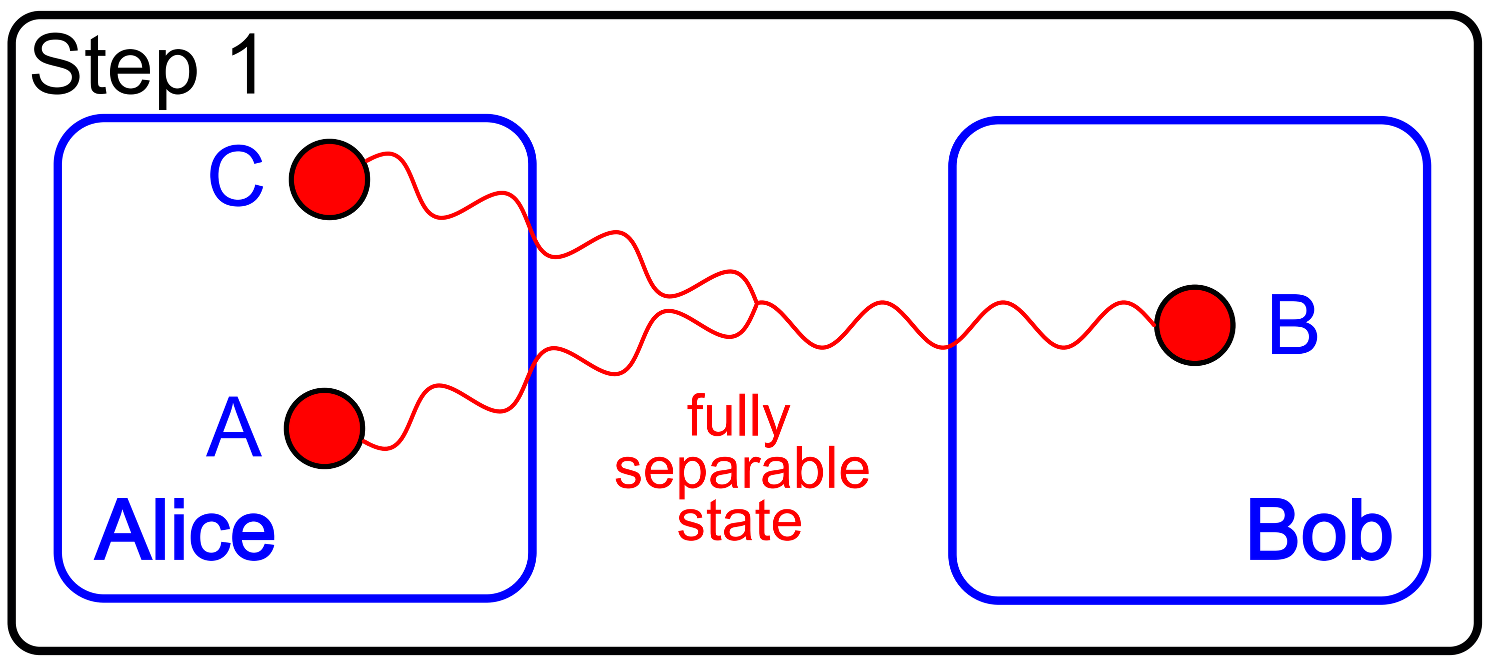
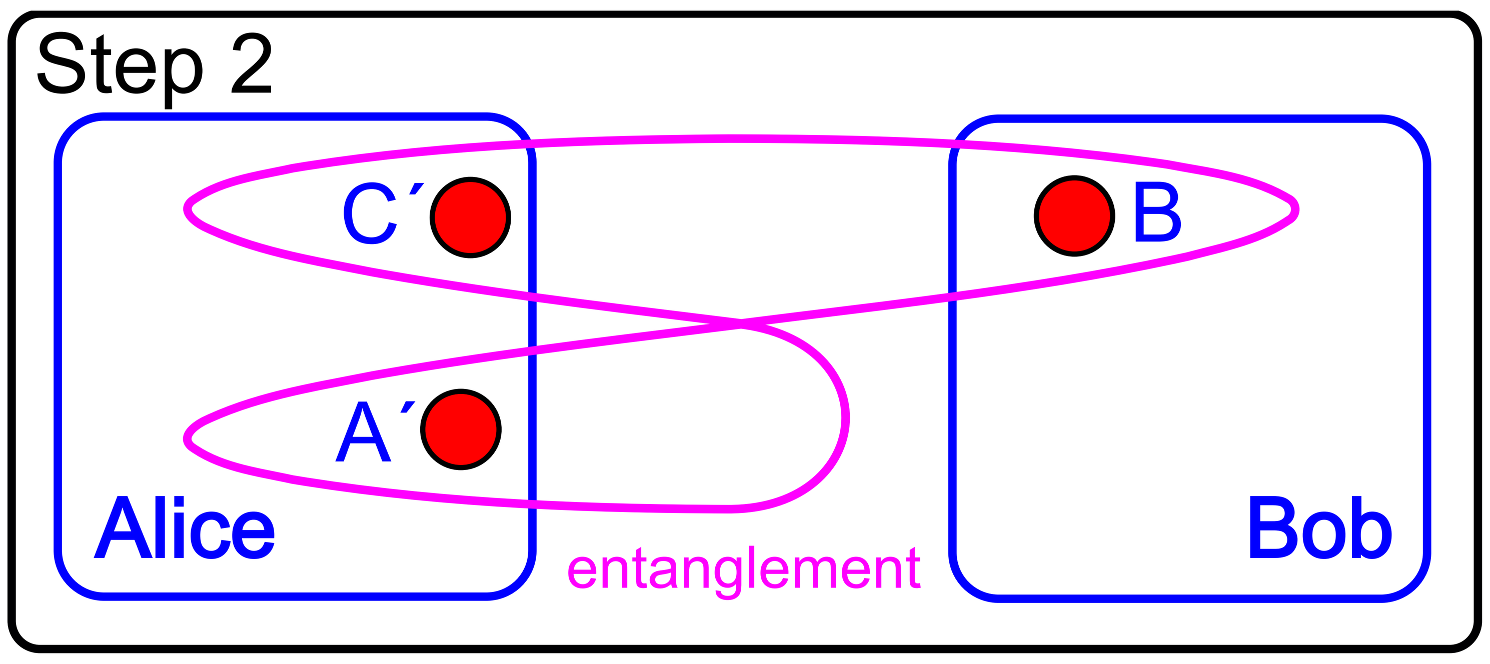
Entanglement distribution by separable states

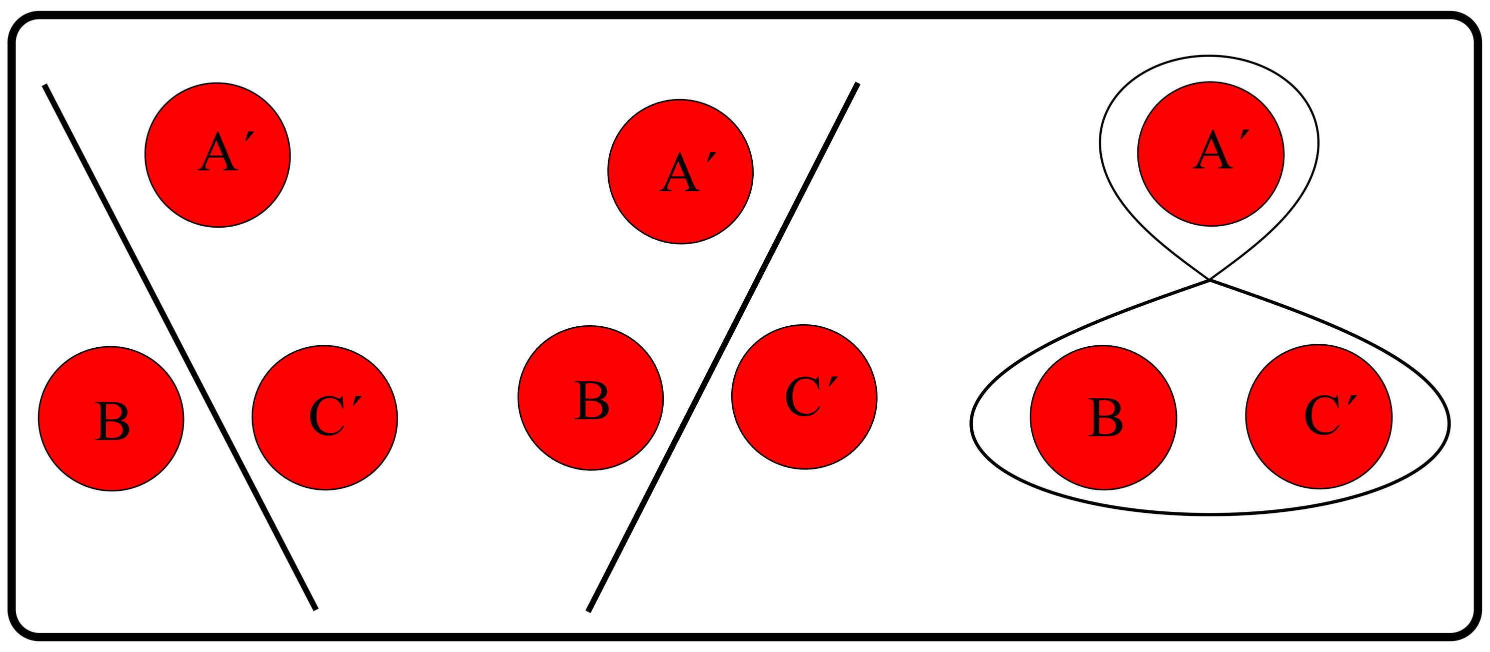
Entanglement distribution without sending entanglement [1].

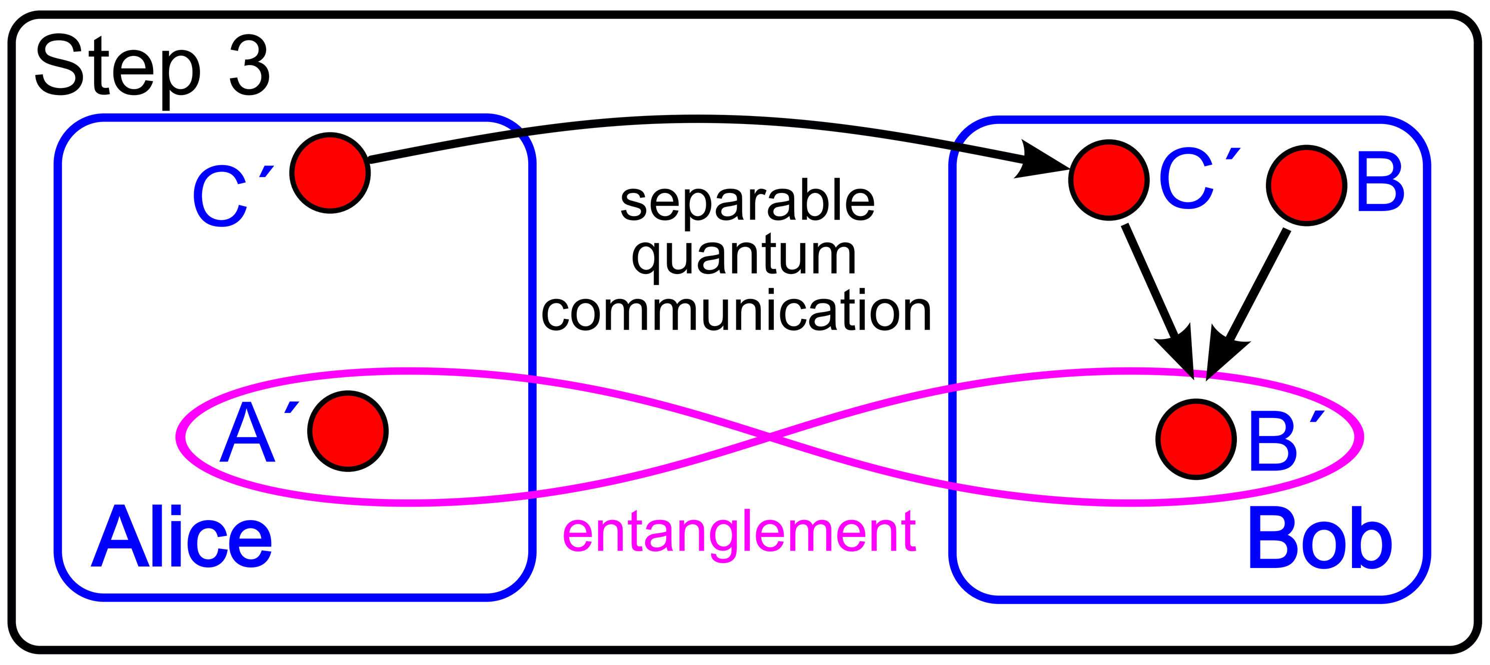
Why is it interesting?

1. Application of multipartite bound entanglement.
2. Construction of new cryptographic concepts [2, 3].
3. Interpretation of quantum discord [4].









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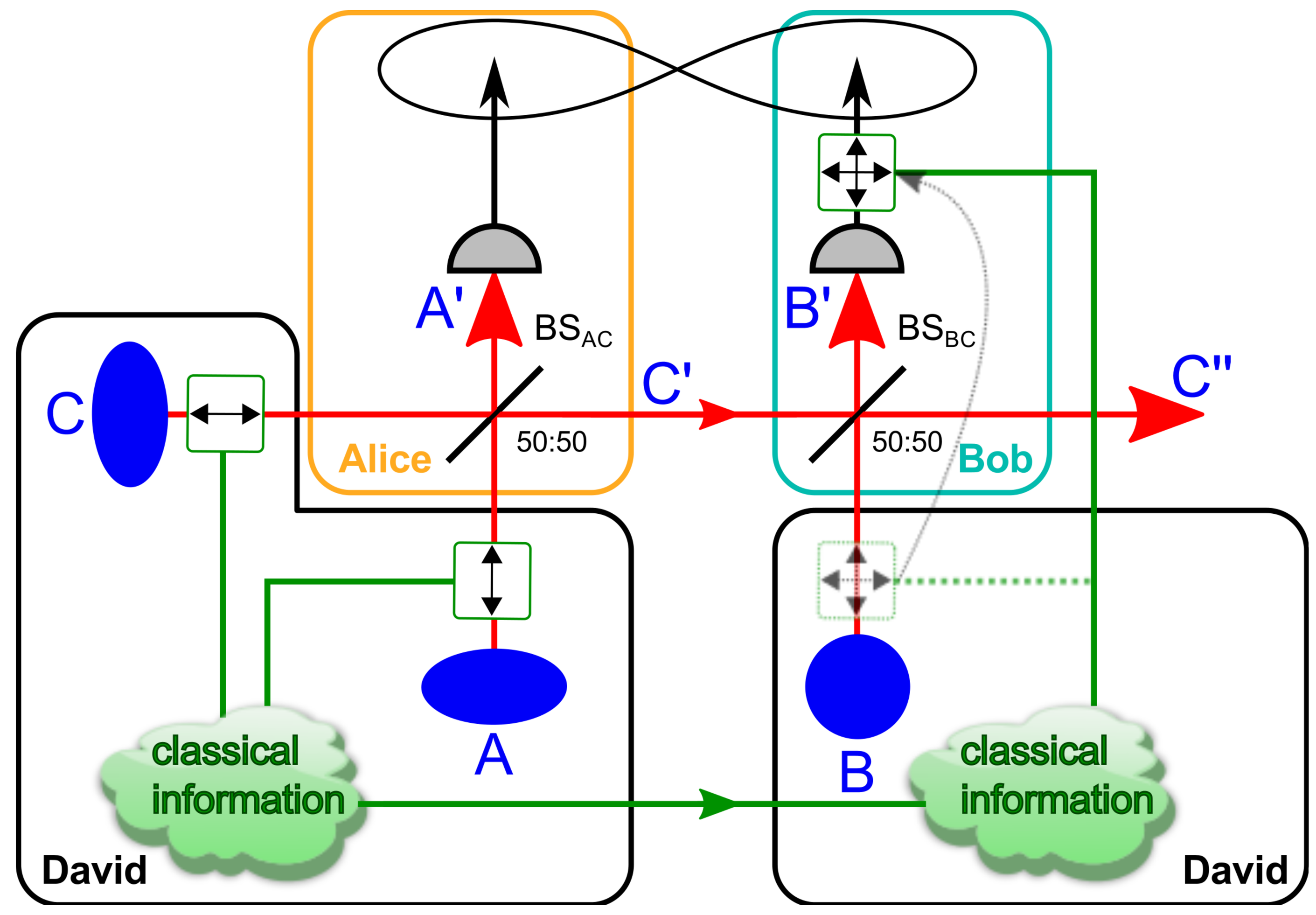
Scheme with squeezed light



Step 1: David prepares a three-mode fully separable state. Modes A and C are squeezed, mode B is vacuum,

$$\hat{x}_{A,C} = e^{\pm r}\hat{x}^{(0)}_{A,C}, \quad \hat{p}_{A,C} = e^{\mp r}\hat{p}^{(0)}_{A,C}, \quad \hat{x}_B = \hat{x}^{(0)}_B, \quad \hat{p}_B = \hat{p}^{(0)}_B,$$

and all modes are displaced by x and p, $\langle x^2\rangle = \langle p^2\rangle = \frac{e^{2r}-1}{2}$, as

$$\hat{p}_A \rightarrow \hat{p}_A - p, \qquad \hat{x}_C \rightarrow \hat{x}_C + x,$$
$$\hat{x}_B \rightarrow \hat{x}_B + \sqrt{2}x, \quad \hat{p}_B \rightarrow \hat{p}_B + \sqrt{2}p.$$

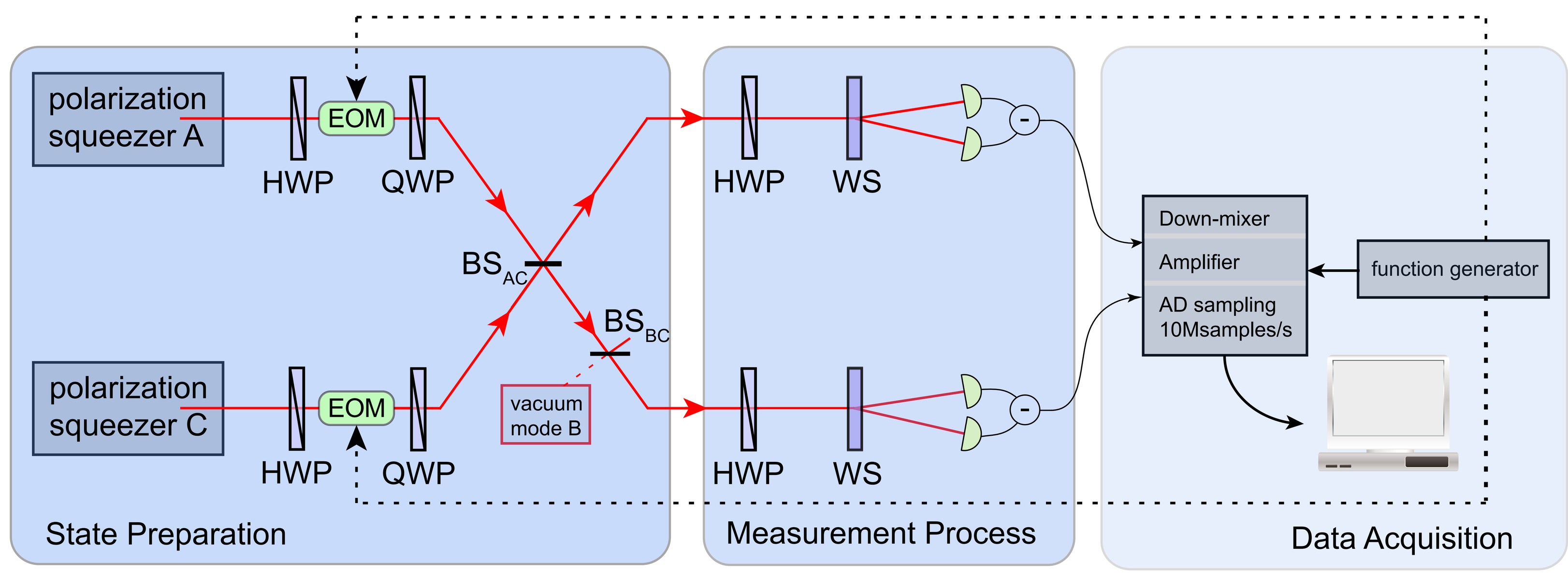
Step 2: Alice creates by a beam splitter BS_{AC} entanglement between A' and (BC') and both C' remains separable from $(A'B)$ and B from $(A'C')$.

Alice sends a separable mode C to Bob.

Step 3: Bob entangles A' with B' by a beam splitter BS_{BC}.

L. Mišta, Jr. and N. Korolkova, Phys. Rev. A **80**, 032310 (2009).

Experiment



Quadratures: $\hat{x} = \frac{\hat{S}_1}{\sqrt{2S_3}}$, $\hat{p} = \frac{\hat{S}_2}{\sqrt{2S_3}}$, $\hat{S}_3 \approx S_3$, $\hat{S}_{1,2,3}$–Stokes operators.

Measurement: covariance matrix γ of modes A', B and C'.

Separability certification in step 2 (PPT criterion [5]):

$$\text{mode } j \text{ is separable} \Leftrightarrow \gamma^{(T_j)} + i\Omega \geq 0,$$

$$\gamma^{(T_j)} = \Lambda_j\gamma\Lambda_j, \quad \Lambda_j = \sigma_z^{(j)} \bigoplus_{k\neq j} I^{(k)}, \quad \Omega = \bigoplus_{i=1}^{3} i\sigma_y.$$

j	A'	B	C'
$\min[\mathrm{eig}(\gamma^{(T_j)} + i\Omega)] \times 10$	-1.44 ± 0.01	5.28 ± 0.03	3.51 ± 0.02

Entanglement recovery in step 3 (product criterion [6]):

$$D \equiv \Delta^2_{\mathrm{norm}}(g\hat{x}_{A'} + \hat{x}_{B'})\Delta^2_{\mathrm{norm}}(g\hat{p}_{A'} - \hat{p}_{B'}) < 1 \Rightarrow A' - B' \text{ entanglement.}$$

$$D = 0.6922 \pm 0.0002 < 1 \text{ for } g_{\mathrm{opt}} = 0.4235 \pm 0.0005$$

Ch. Peuntinger, V. Chille, L. Mišta, Jr., N. Korolkova, M. Förtsch, J. Korger, Ch. Marquardt, and G. Leuchs, Phys. Rev. Lett. **111**, 230506 (2013). Two more experiments [7, 8].