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EQUS

More on encoding and decoding, and a little bit more on high-d entanglement…

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Scholars

Australian Government
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For Women in Science
FONDATION L'ORÉAL

Plan…

Introduce/review dense coding and teleportation

Two experiments on dense coding, one using hyperentanglement

Introduce quantum secret sharing

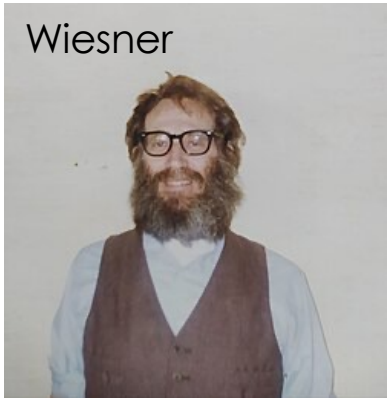
What is quantum?

The Bull, Picasso 1945

"Quantumness" allows for quantum encoding and decoding.

Quantum dense coding

Quantum teleportation



wikipedia

Bennett and Weisner, Phys. Rev. Lett. 1992
Bennett et al. Phys. Rev, Lett., 1993

Quantum dense coding=“inverse” of quantum teleportation

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Two experiments on dense coding, one using hyperentanglement

Introduce quantum secret sharing

Experimental dense coding

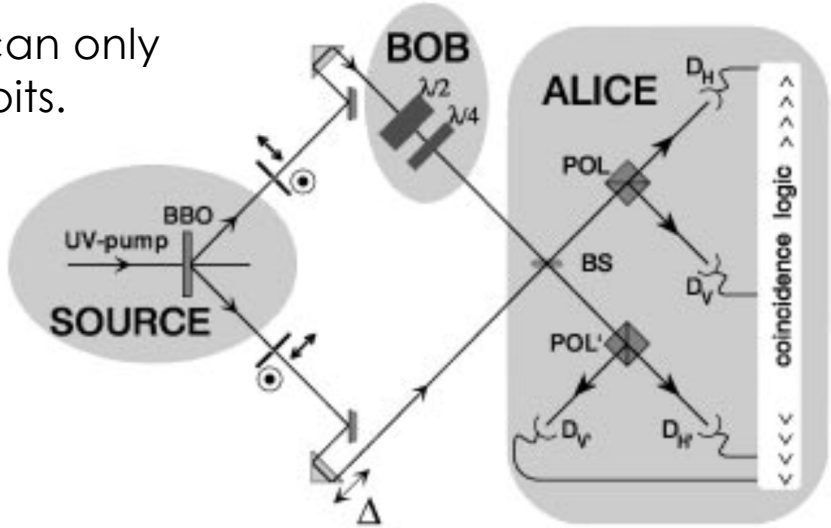
VOLUME 76, NUMBER 25 PHYSICAL REVIEW LETTERS 17 JUNE 1996

Dense Coding in Experimental Quantum Communication

Klaus Mattle,[1] Harald Weinfurter,[1] Paul G. Kwiat,[1,2] and Anton Zeilinger[1]
[1]*Institut für Experimentalphysik, Universität Innsbruck, A-6020 Innsbruck, Austria*
[2]*Los Alamos National Laboratory, P-23, MS-H803, Los Alamos, New Mexico 87545*
(Received 22 November 1995)

$$|\Psi^+\rangle = (|H\rangle|V\rangle + |V\rangle|H\rangle)/\sqrt{2},$$
$$|\Psi^-\rangle = (|H\rangle|V\rangle - |V\rangle|H\rangle)/\sqrt{2},$$
$$|\Phi^+\rangle = (|H\rangle|H\rangle + |V\rangle|V\rangle)/\sqrt{2},$$
$$|\Phi^-\rangle = (|H\rangle|H\rangle - |V\rangle|V\rangle)/\sqrt{2}.$$

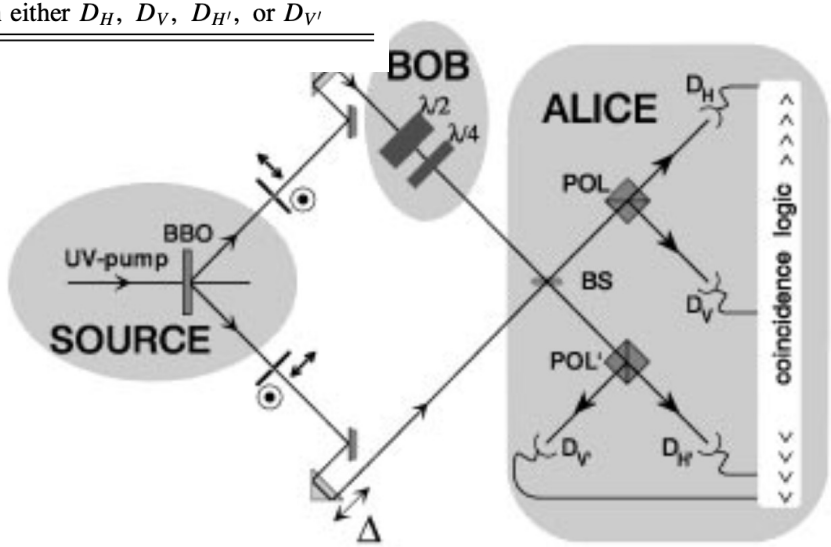
With linear optics, one can only transmit 1.58 bits, not 2 bits.

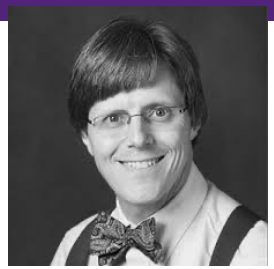


Experimental dense coding

TABLE I. Overview of possible manipulations and detection events of the quantum dense coding experiment with correlated photons (we use h to denote the state of a photon in the mode towards detector D_H, etc.).

Bob's setting				
$\lambda/2$	$\lambda/4$	State sent	State at output of Bell-state analyzer	Alice's registration events
0°	0°	$\|\Psi^+\rangle$	$\{hv + h'v' + vh + v'h'\}/2$	Coincidence between D_H *and* D_V or $D_{H'}$ *and* $D_{V'}$
0°	90°	$\|\Psi^-\rangle$	$\{hv' - h'v' + v'h - vh'\}/2$	Coincidence between D_H *and* $D_{V'}$ or $D_{H'}$ *and* D_V
45°	0°	$\|\Phi^+\rangle$	$\{hh + vv + h'h' + v'v'\}/2$	2 photons in either D_H, D_V, $D_{H'}$, or $D_{V'}$
45°	90°	$\|\Phi^-\rangle$	$\{hh - vv + h'h' + v'v'\}/2$	2 photons in either D_H, D_V, $D_{H'}$, or $D_{V'}$





Experimental dense coding

nature physics

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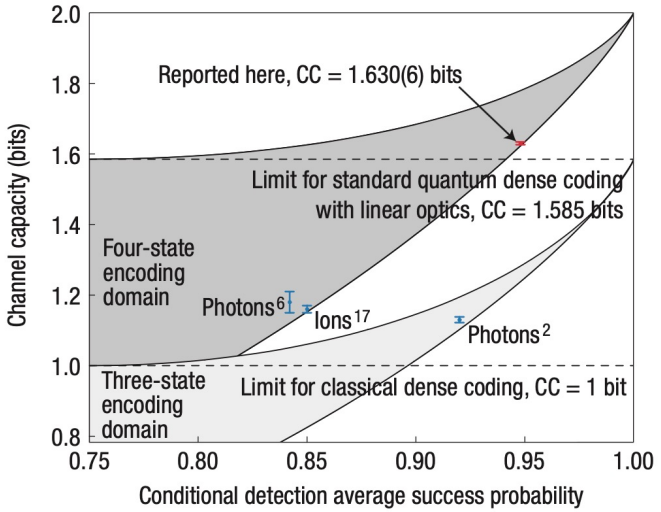
Letter | Published: 23 March 2008

Beating the channel capacity limit for linear photonic superdense coding

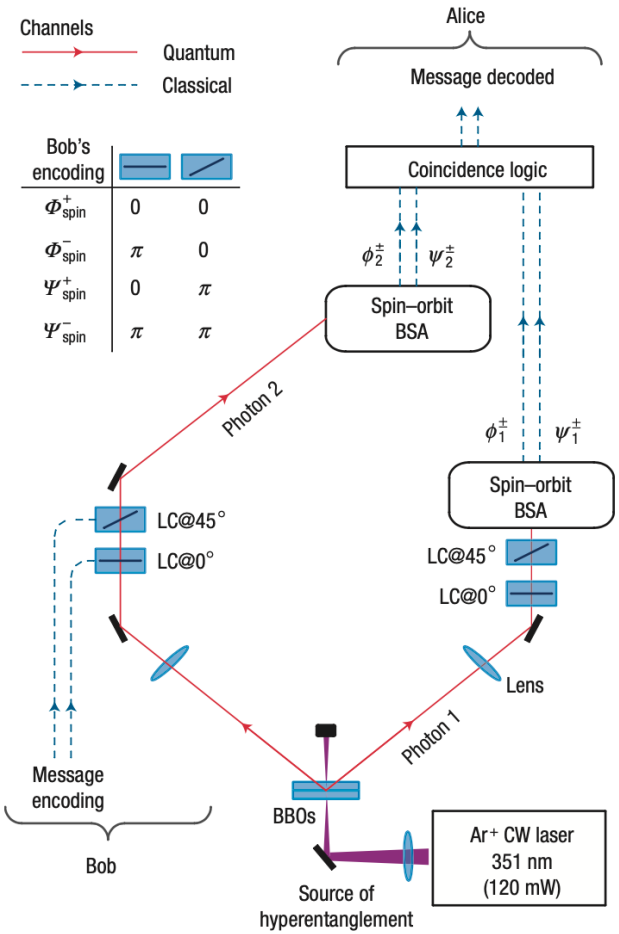
Julio T. Barreiro ✉, Tzu-Chieh Wei & Paul G. Kwiat

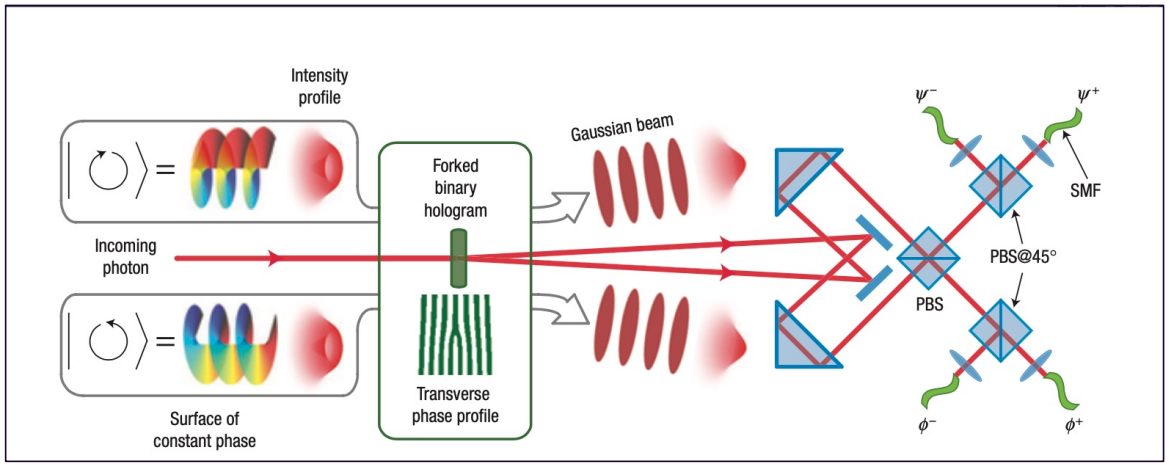
Nature Physics **4**, 282–286 (2008) | Cite this article

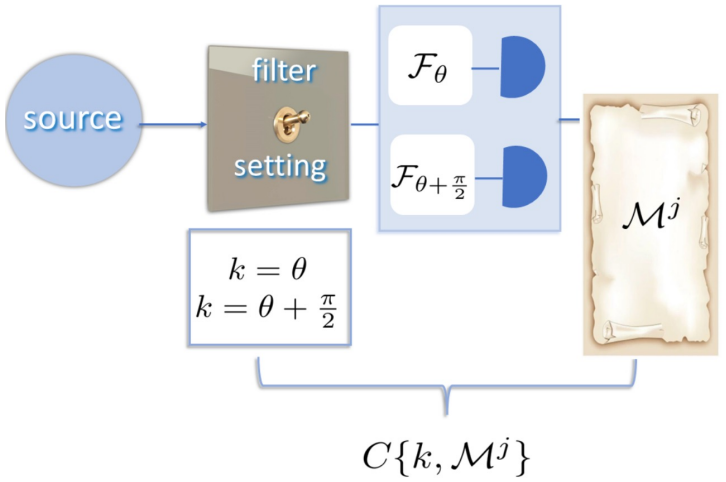


$$\frac{1}{2}(|HH\rangle + |VV\rangle) \otimes (|\circlearrowleft\circlearrowleft\rangle + |\circlearrowright\circlearrowright\rangle)$$

With hyper-entanglemen (simultaneously entangled in two degrees of freedom), one can only transmit 1.630 bits, above the 1.585 bits limit.







$$C\{k, \mathcal{M}^j\}$$

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Benefits: Why use qudits/entangled qudits?

- higher information capacity $2^{10} = 1024 = 32^2$
- more robust against optimal cloning $F^d_{clon} = \frac{1}{2} + \frac{1}{1+d}$
- higher QKD error thresholds $d = 2 \quad 11\%$ $d = 4 \quad 22\%$

What can be done *only* with qudits?

What can be done *only* with qudit entanglement?

Erhard et al, Light Sci Appl 7 17146(2018)

What can you do *only* with high-dimensional entanglement?

VOLUME 83, NUMBER 3 PHYSICAL REVIEW LETTERS 19 JULY 1999

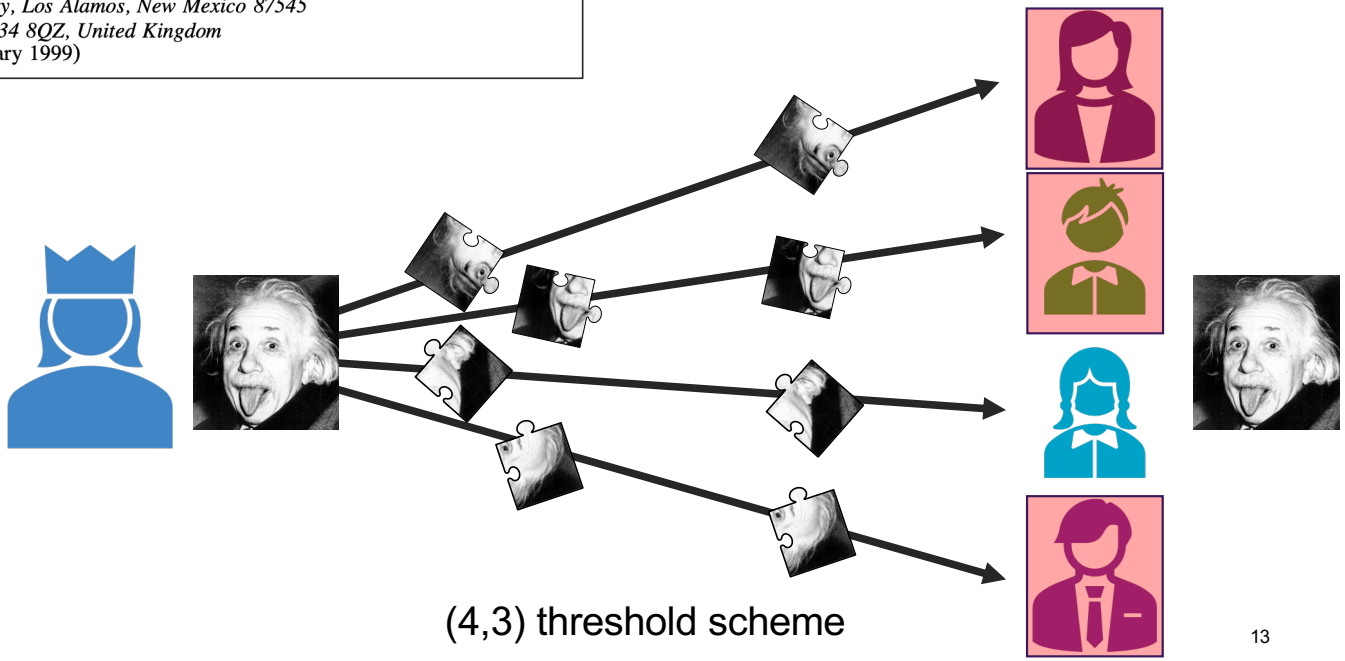
How to Share a Quantum Secret

Richard Cleve,[1,*] Daniel Gottesman,[2,†] and Hoi-Kwong Lo[3,‡]
[1]*Department of Computer Science, University of Calgary, Calgary, Alberta, Canada T2N 1N4*
[2]*T-6 Group, Los Alamos National Laboratory, Los Alamos, New Mexico 87545*
[3]*Hewlett-Packard Labs, Bristol BS34 8QZ, United Kingdom*
(Received 11 January 1999)

N=number of parties
K=number of trusted parties

A (3,2) threshold scheme using qubit shares does not exist.

Entangled qutrits are necessary!



(4,3) threshold scheme

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How to Share a Quantum Secret

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[1]*Department of Computer Science, University of Calgary, Calgary, Alberta, Canada T2N 1N4*
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[3]*Hewlett-Packard Labs, Bristol BS34 8QZ, United Kingdom*
(Received 11 January 1999)

Physical Review A

Approximate reconstructability of quantum states and noisy quantum secret sharing schemes

Yingkai Ouyang [1,2,*], Kaumudibikash Goswami [3,4], Jacquiline Romero[3], Barry C. Sanders [5,4,†], Min-Hsiu Hsieh[6,‡], and Marco Tomamichel [2,7]

Note that the above example is similar to a quantum error-correcting code [7,8]. In fact, it is a three-qutrit quantum code that can correct one erasure error. Every quantum secret sharing scheme is, in some sense, a quantum error-correcting code; however, some error-correcting codes are not secret sharing schemes, since they may contain sets of shares from which *partial* information about the secret can be obtained. For example, consider a four-qubit code [9,10] that corrects one erasure by the encoding

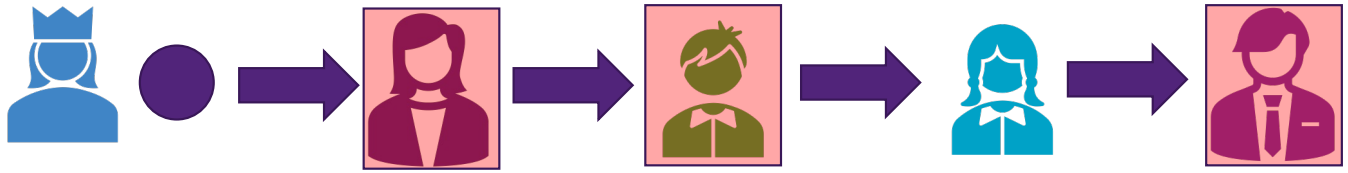
$$\alpha|0\rangle + \beta|1\rangle \mapsto \alpha(|0000\rangle + |1111\rangle) + \beta(|0011\rangle + |1100\rangle).$$

What can you do *only* with qudits?

PHYSICAL REVIEW A **92**, 030302(R) (2015)

Secret sharing with a single *d*-level quantum system

Armin Tavakoli,[1] Isabelle Herbauts,[1] Marek Żukowski,[2] and Mohamed Bourennane[1]
[1]*Department of Physics, Stockholm University, SE-10691 Stockholm, Sweden*
[2]*Institute of Theoretical Physics and Astrophysics, Uniwersytet Gdański, PL-80-952 Gdańsk, Poland*
(Received 22 January 2015; revised manuscript received 27 March 2015; published 21 September 2015)



Quantum secret sharing with **just one** detector is possible with qudits.

Is that quantum error correction?

LETTER ARTICLE

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www.lpr-journal.org

Experimental Demonstration of 11-Dimensional 10-Party Quantum Secret Sharing

*Jonathan Pinnell, Isaac Nape, Michael de Oliveira, Najmeh TabeBordbar, and Andrew Forbes**

Take home…

- Dense coding is the "inverse" of teleportation. You can communicate 2 bits with 1 qubit, given there is pre-shared entanglement.
- Dense coding experiments with photons are currently below the 2-bit optimum value. Hyperentanglement can help achieve this limit.
- Quantum secret sharing is somewhat quantum error correction.

Thank you!