Vol 11 No 10, October 2002
1009-1963/2002/11(10)/0999-05

Chinese Physics

© 2002 Chin. Phys. Soc.
and IOP Publishing Ltd

Teleportation of an arbitrary three-particle state*

Chen Li-Bing(陈立冰)

Key Laboratory of Information, Chinese Academy of Sciences, University of Science and Technology of China, Hefei 230026, *China*

Department of Physics, Foshan University, Foshan 528000, *China*

(Received 30 January 2002; revised manuscript received 3 June 2002)

We propose two schemes for teleporting an arbitrary three-particle state. In the first scheme, a two-particle state and a three-particle entangled state (both non-maximally entangled states) are used as quantum channels, while in the second scheme, three non-maximally entangled particle pairs are employed as quantum channels. We show that teleportation can be successfully realized with certain probability if a receiver adopts some appropriate unitary transformations. Their success probabilities and the classical communication costs are different.

Keywords: teleportation, entangled state, probability, unitary transformation
PACC: 0365

Since first suggested by Bennett *et al*,[1] quantum state teleportation has attracted the attention of both theorists and experimentalists. It is one of the most important aspects of quantum information. In the teleportation process, an unknown quantum state is transferred without material transportation from a sender, Alice, to a receiver, Bob, via a quantum channel with the help of some classical information. Based on the quantum teleportation protocol, quantum teleportation of a qubit encoded in the polarization state of single photons has been demonstrated experimentally by Bouwmeester *et al*[2] and Boschi *et al*[3] using parametric down-conversion. Davidovich *et al*[4] have proposed a scheme for the teleportation of an unknown atomic state between two high-Q cavities initially prepared in an entangled Fock state. Cirac *et al*[5] and others[6−11] have made other proposals for the quantum teleportation of an atomic state or field state.

Another interesting problem is how to teleport a multi-particle state. Multi-particle quantum teleportation may be extremely useful in quantum computation and quantum communication. In Refs.[12] and [13], the schemes of teleporting a two-particle state have been proposed. Recently, Yang *et al*[14] and Lu[15] proposed schemes for teleporting a three-particle entangled Greenberger–Horne–Zeilinger (GHZ) type state.[16] But to date, there has been no proposal for how to probabilistically teleport an arbitrary three-particle state. In this paper, we present two schemes by which the probabilistic teleportation of an unknown arbitrary three-particle state can be realized. One scheme is actually obtained by generalizing the scheme of Li *et al*[17] to the three-particle case, in which three non-maximally entangled particle pairs are used as quantum channels. In the other scheme, a three-particle and a two-particle entangled state (both non-maximally entangled states) are used as quantum channels. The successful probabilities of these two schemes are different.

We describe the two schemes respectively as follow.

Alice has an unknown arbitrary three-particle state $|\psi\rangle_{123}$ that she wants to teleport to Bob

$$\begin{aligned}|\psi\rangle_{123} =&\lambda_0|001\rangle_{123} + \lambda_1|010\rangle_{123} \\ &+ \lambda_2|100\rangle_{123} + \lambda_3|000\rangle_{123} \\ &\lambda_4|110\rangle_{123} + \lambda_5|101\rangle_{123} \\ &+ \lambda_6|011\rangle_{123} + \lambda_7|111\rangle_{123}, \end{aligned} \quad (1)$$

where $\sum_{i=0}^{7}|\lambda_i|^2 = 1$, $\{|001\rangle, |010\rangle, |100\rangle, |000\rangle, |110\rangle, |101\rangle, |011\rangle, |111\rangle\}$ is the basis of a eight-dimensional Hilbert space.

First, we use a two-particle entangled state $|\psi\rangle_{45}$ and a three-particle entangled state $|\psi\rangle_{678}$ (both non-maximally entangled) to do the job. Without losing generality, we suppose that particles 4 and 5 and particles 6, 7 and 8 are respectively located in the following

*Project supported by the National Natural Science Foundation of China (Grant No 19874056).

states

$$|\psi\rangle_{45} = a|00\rangle_{45} + b|11\rangle_{45}, \tag{2}$$

$$|\psi\rangle_{678} = c|000\rangle_{678} + d|111\rangle_{678}, \tag{3}$$

where $|a| > |b|$, $|a|^2 + |b|^2 = 1$; $|c| > |d|$, $|c|^2 + |d|^2 = 1$. We give particles 4 and 6 to Alice and particles 5, 7 and 8 to Bob, the state of the whole system at this moment being

$$|\psi\rangle = |\psi\rangle_{123}|\psi\rangle_{45}|\psi\rangle_{678}. \tag{4}$$

In order to realize teleportation, a combined measurement on Alice's five particles is needed. The combined measurement includes a Bell-state measurement on particles (3, 4), particles (1, 6), respectively, and a separate measurement on particle 2 in the $\{|\pi_0\rangle, |\pi_1\rangle\}$ basis defined by

$$\begin{pmatrix} |\pi_0\rangle \\ |\pi_1\rangle \end{pmatrix} = \frac{1}{\sqrt{2}} \begin{pmatrix} 1 & 1 \\ 1 & -1 \end{pmatrix} \begin{pmatrix} |0\rangle \\ |1\rangle \end{pmatrix}, \tag{5}$$

which will project particles 5, 7, and 8 on to one of the following non-normalization states (32 kinds in all)

$$|\psi\rangle_{578} = \langle\pi_k|_2\langle\varphi|_{16}\langle\varphi|_{34}\psi\rangle, \tag{6}$$

where $k = 0, 1$; $|\varphi\rangle_{ij}$ is the Bell state ($|\varphi\rangle_{ij} = |\phi^{\pm}\rangle_{ij}, |\psi^{\pm}\rangle_{ij}$)[18] in which the particles (i, j) are measured.

After this, Alice informs Bob of her measurement results via a classical channel, which obviously requires five classical bits. Next, Bob tries to reconstruct the original state with his particles 5, 7 and 8. Firstly, Bob needs to establish a correspondence so that the coefficients λ_0, λ_1, λ_2, λ_3, λ_4, λ_5, λ_6, and λ_7, correspond to $|001\rangle_{578}$, $|010\rangle_{578}$, $|100\rangle_{578}$, $|000\rangle_{578}$, $|110\rangle_{578}$, $|101\rangle_{578}$, $|011\rangle_{578}$, and $|111\rangle_{578}$, respectively. This can be achieved by performing a unitary transformation U_1 on particles 5, 7 and 8. Secondly, Bob introduces an auxiliary qubit A with the original state $|0\rangle_A$ and operates another unitary transformation U_2 under the basis $\{|0010\rangle_{578A}$, $|0100\rangle_{578A}$, $|1000\rangle_{578A}$, $|0000\rangle_{578A}$, $|1100\rangle_{578A}$, $|1010\rangle_{578A}$, $|0110\rangle_{578A}$, $|1110\rangle_{578A}$, $|0011\rangle_{578A}$, $|0101\rangle_{578A}$, $|1001\rangle_{578A}$, $|0001\rangle_{578A}$, $|1101\rangle_{578A}$, $|1011\rangle_{578A}$, $|0111\rangle_{578A}$, $|1111\rangle_{578A}\}$, namely

$$U_2 = \begin{pmatrix} A_1 & A_2 \\ A_2 & -A_1 \end{pmatrix}, \tag{7a}$$

where A_i (i=1,2) is a 8×8 matrix and may be expressed as

$$A_1 = \mathrm{diag}(a_0, a_1, a_2, a_3, a_4, a_5, a_6, a_7,), \tag{7b}$$

$$A_2 = \mathrm{diag}\Big(\sqrt{1-a_0^2}, \sqrt{1-a_1^2}, \sqrt{1-a_2^2}, \sqrt{1-a_3^2}, \sqrt{1-a_4^2}, \sqrt{1-a_5^2}, \sqrt{1-a_6^2}, \sqrt{1-a_7^2}\Big). \tag{7c}$$

Here a_i (i=0,1,2,3,4,5,6,7 and $|a_i| \leq 1$) depends on the state of particles 5, 7 and 8. The unitary transformations U_1 and U_2 will transform the non-normalized product state

$$|\psi\rangle_{578} \otimes |0\rangle_A = \langle\pi_k|_2\langle\varphi|_{16}\langle\varphi|_{34}\psi\rangle \otimes |0\rangle_A \tag{8}$$

into

$$\frac{1}{2\sqrt{2}} bd(|R\rangle_{578}|0\rangle_A + |W\rangle_{578}|1\rangle_A), \tag{9}$$

where $|R\rangle_{578}$ is the desired state and $|W\rangle_{578}$ is the wrong state.

Finally, Bob measures the state of particle A. For Eq.(9), if the result is $|1\rangle_A$, the teleportation fails. Otherwise the result is $|0\rangle_A$, and the state of particles 5, 7 and 8 collapses to

$$\begin{aligned} \frac{1}{2\sqrt{2}} bd|R\rangle_{578} =& \frac{1}{2\sqrt{2}} bd(\lambda_0|001\rangle_{578} + \lambda_1|010\rangle_{578} \\ &+ \lambda_2|100\rangle_{578} + \lambda_3|000\rangle_{578} \\ &+ \lambda_4|110\rangle_{578} + \lambda_5|101\rangle_{578} \\ &+ \lambda_6|011\rangle_{578} + \lambda_7|111\rangle_{578}), \end{aligned} \tag{10}$$

and teleportation is successfully realized with the probability $|bd|^2/8$.

For instance, if Alice's measurement results are $|\varphi\rangle_{34} = |\phi^-\rangle_{34}$, $|\varphi\rangle_{16} = |\phi^+\rangle_{16}$, $|\pi_k\rangle_2 = |\pi_0\rangle_2$, the state of particles 5, 7 and 8, as shown by Eq.(6), is

$$\begin{aligned} |\psi\rangle_{578} =& \langle\pi_0|_2\langle\phi^+|_{16}\langle\phi^-|_{34}\psi\rangle \\ =& \frac{1}{2\sqrt{2}}(-bc\lambda_0|100\rangle_{578} + ac\lambda_1|000\rangle_{578} \\ &+ ad\lambda_2|011\rangle_{578} + ac\lambda_3|000\rangle_{578} \\ &+ ad\lambda_4|011\rangle_{578} - bd\lambda_5|111\rangle_{578} \\ &- bc\lambda_6|100\rangle_{578} - bd\lambda_7|111\rangle_{578}). \end{aligned} \tag{11}$$

The corresponding unitary transformation

$$\begin{aligned} U_1 =& (|0\rangle\langle 1|_{\lambda_0} + |1\rangle\langle 0|_{\lambda_2} + |1\rangle\langle 0|_{\lambda_4} + |0\rangle\langle 1|_{\lambda_6})_5 \\ &\otimes (|1\rangle\langle 0|_{\lambda_1} + |0\rangle\langle 1|_{\lambda_2} + |0\rangle\langle 1|_{\lambda_5} + |1\rangle\langle 0|_{\lambda_6})_7 \\ &\otimes (|1\rangle\langle 0|_{\lambda_0} + |0\rangle\langle 1|_{\lambda_2} + |0\rangle\langle 1|_{\lambda_4} + |1\rangle\langle 0|_{\lambda_6})_8 \end{aligned} \tag{12}$$

(here, subscript λ_i shows that we put a Pauli operator 'σ_x' on the state whose coefficient is λ_i) will transform the state shown by Eq.(11) into

$$\begin{aligned} |\psi\rangle_{578} =& \frac{1}{2\sqrt{2}}(-bc\lambda_0|001\rangle_{578} + ac\lambda_1|010\rangle_{578} \\ &+ ad\lambda_2|100\rangle_{578} + ac\lambda_3|000\rangle_{578} \\ &+ ad\lambda_4|110\rangle_{578} - bd\lambda_5|101\rangle_{578} \\ &- bc\lambda_6|011\rangle_{578} - bd\lambda_7|111\rangle_{578}), \end{aligned} \tag{13}$$

and the state shown by Eq.(8) is

$$\begin{aligned}|\psi\rangle_{578}\otimes|0\rangle_A =&\frac{1}{2\sqrt{2}}(-bc\lambda_0|001\rangle_{578}+ac\lambda_1|010\rangle_{578}\\&+ad\lambda_2|100\rangle_{578}+ac\lambda_3|000\rangle_{578}\\&+ad\lambda_4|110\rangle_{578}-bd\lambda_5|101\rangle_{578}\\&-bc\lambda_6|011\rangle_{578}-bd\lambda_7|111\rangle_{578})|0\rangle_A.\end{aligned}\tag{14}$$

For Eq.(7), if we take

$$\begin{aligned}&(a_0,a_1,a_2,a_3,a_4,a_5,a_6,a_7)\\=&\left(-\frac{d}{c},\frac{bd}{ac},\frac{b}{a},\frac{bd}{ac},\frac{b}{a},-1,-\frac{d}{c},-1\right)\end{aligned}\tag{15}$$

(a_i can be determined by dividing bd by the coefficient of the ith term shown in Eq.(14), for instance, $a_6=\dfrac{bd}{-bc}=-\dfrac{d}{c}$), the unitary transformation U_2 will transform the state shown in Eq.(14) into

$$\begin{aligned}&\frac{bd}{2\sqrt{2}}\Big\{(\lambda_0|001\rangle_{578}+\lambda_1|010\rangle_{578}+\lambda_2|100\rangle_{578}\\&+\lambda_3|000\rangle_{578}+\lambda_4|110\rangle_{578}+\lambda_5|101\rangle_{578}\\&+\lambda_6|011\rangle_{578}+\lambda_7|111\rangle_{578})|0\rangle_A\\&+\Big[-\frac{c}{d}\sqrt{1-\frac{d^2}{c^2}}(\lambda_0|001\rangle_{578}+\lambda_6|100\rangle_{578})\\&+\frac{ac}{bd}\sqrt{1-\left(\frac{bd}{ac}\right)^2}(\lambda_1|010\rangle_{578}+\lambda_3|000\rangle_{578})\\&+\frac{a}{b}\sqrt{1-\frac{b^2}{a^2}}(\lambda_2|100\rangle_{578}+\lambda_4|110\rangle_{578})\Big]|1\rangle_A\Big\}.\end{aligned}$$

So Bob has $\dfrac{1}{8}|bd|^2$ probability to obtain the desired state $|R\rangle_{578}$.

In fact, U_1 and U_2 can be incorporated into a single transformation

$$U=U_2(U_1\otimes I_A).\tag{16}$$

It has been shown that such a unitary transformation can be decomposed into universal quantum logic operations[19] that have been experimentally realized in some physical systems.[20]

It can be easily verified that 32 kinds of states shown in Eq.(6) have the same results, therefore the total probability of successful teleportation is $4|bd|^2$. This means that the probability of successful teleportation is determined by the smaller Schmidt coefficients of the entangled states which are used as quantum channels. If $|a|=|b|=|c|=|d|=\dfrac{1}{\sqrt{2}}$, the total probability reaches one. That is to say, if the quantum channels are composed of an EPR state and a three-particle GHZ state, complete teleportation can be realized by this method.

Now, we turn to the other scheme. Suppose the state that Alice wants to teleport is still in state (1), but the three pairs of entangled particles shared by Alice (particles 4, 6 and 8) and Bob (particles 5, 7 and 9) are employed as quantum channels

$$\begin{aligned}|\psi\rangle_{45}&=a|00\rangle_{45}+b|11\rangle_{45},\\|\psi\rangle_{67}&=c|00\rangle_{67}+d|11\rangle_{67},\\|\psi\rangle_{89}&=e|00\rangle_{89}+f|11\rangle_{89},\end{aligned}\tag{17}$$

where $|a|>|b|, |a|^2+|b|^2=1$; $|c|>|d|, |c|^2+|d|^2=1$; $|e|>|f|, |e|^2+|f|^2=1$. Therefore, the state of the system reads as

$$|\psi\rangle=|\psi\rangle_{123}|\psi\rangle_{45}|\psi\rangle_{67}|\psi\rangle_{89}.\tag{18}$$

First, Alice performs a Bell-state measurement on particles (1, 4), (2, 6) and (3, 8) respectively. Then the state of particles 5, 7, and 9 will collapse into one of the following states (64 kinds in all)

$$|\psi\rangle_{579}=\langle\varphi|_{38}\langle\varphi|_{26}\langle\varphi|_{14}\psi\rangle.\tag{19}$$

Alice informs Bob of her measurement results via a classical channel, which requires six bits. Similar to the scheme described above, Bob introduces an auxiliary qubit A with the original state $|0\rangle_A$. The unitary transformation U shown in Eq.(16) will transform the non-normalized product state

$$|\psi\rangle_{579}\otimes|0\rangle_A=\langle\varphi|_{38}\langle\varphi|_{26}\langle\varphi|_{14}\psi\rangle\otimes|0\rangle_A\tag{20}$$

into

$$\frac{1}{2\sqrt{2}}bdf(|R\rangle_{579}|0\rangle_A+|W\rangle_{579}|1\rangle_A).\tag{21}$$

Admittedly, Bob has $\dfrac{1}{8}|bdf|^2$ probability to obtain state $|R\rangle_{579}$. For instance, if Alice's measurement results are $|\varphi\rangle_{14}=|\phi^+\rangle_{14}$, $|\varphi\rangle_{26}=|\phi^+\rangle_{26}$ and $|\varphi\rangle_{38}=|\psi^-\rangle_{38}$, the state of particles 5, 7 and 9 shown in Eq.(19) is

$$\begin{aligned}|\psi\rangle_{579}=&\langle\psi^-|_{38}\langle\phi^+|_{26}\langle\phi^+|_{14}\psi\rangle\\=&\frac{1}{2\sqrt{2}}(-ace\lambda_0|000\rangle_{579}+adf\lambda_1|011\rangle_{579}\\&+bcf\lambda_2|101\rangle_{579}+acf\lambda_3|001\rangle_{579}\\&+bdf\lambda_4|111\rangle_{579}-bce\lambda_5|100\rangle_{579}\\&-adf\lambda_6|010\rangle_{579}-bdf\lambda_7|110\rangle_{579}).\end{aligned}\tag{22}$$

The corresponding unitary transformation $U_1 = I_5 \otimes I_7 \otimes (\sigma_x)_9$ will transform state (22) into

$$\begin{aligned}|\psi\rangle_{579} =& \frac{1}{2\sqrt{2}}(-ace\lambda_0|001\rangle_{578} + adf\lambda_1|010\rangle_{578} \\ &+ bcf\lambda_2|100\rangle_{578} + acf\lambda_3|000\rangle_{578} \\ &+ bdf\lambda_4|110\rangle_{578} - bce\lambda_5|101\rangle_{578} \\ &- adf\lambda_6|011\rangle_{578} - bdf\lambda_7|111\rangle_{578}). \end{aligned} \quad (23)$$

For Eq.(7), if we take

$$\begin{aligned}&(a_0, a_1, a_2, a_3, a_4, a_5, a_6, a_7) \\ =&\left(-\frac{bdf}{ace}, \frac{b}{a}, \frac{d}{c}, \frac{bd}{ac}, 1, -\frac{df}{ce}, -\frac{b}{a}, -1 \right) \end{aligned} \quad (24)$$

(a_i can be determined by dividing bdf by the coefficient of the ith term shown in Eq.(23), for instance, $a_3 = \dfrac{bdf}{acf} = \dfrac{bd}{ac}$), the unitary transformation U_2 will transform the state $|\psi\rangle_{579}|0\rangle_A$ into

$$\begin{aligned}&\frac{bdf}{2\sqrt{2}}\Big\{(\lambda_0|001\rangle_{579} + \lambda_1|010\rangle_{579} + \lambda_2|100\rangle_{579} \\ &+ \lambda_3|000\rangle_{579} + \lambda_4|110\rangle_{579} + \lambda_5|101\rangle_{579} \\ &+ \lambda_6|011\rangle_{579} + \lambda_7|111\rangle_{579})|0\rangle_A \\ &+ \Big[-\lambda_0\frac{ace}{bdf}\sqrt{1-\left(\frac{bdf}{ace}\right)^2}|001\rangle_{579} \\ &+ \lambda_1\frac{a}{b}\sqrt{1-\left(\frac{b}{a}\right)^2}|010\rangle_{579} \\ &+ \lambda_2\frac{c}{d}\sqrt{1-\left(\frac{d}{c}\right)^2}|100\rangle_{579} \\ &+ \lambda_3\frac{ac}{bd}\sqrt{1-\left(\frac{bd}{ac}\right)^2}|000\rangle_{579} \\ &- \lambda_5\frac{e}{f}\sqrt{1-\left(\frac{df}{ce}\right)^2}|101\rangle_{579} \\ &- \lambda_6\sqrt{1-\left(\frac{b}{a}\right)^2}|011\rangle_{579}\Big]|1\rangle_A\Big\}, \end{aligned}$$

and Bob has $\dfrac{1}{8}|bdf|^2$ probability to obtain the desired state $|R\rangle_{579}$. Synthesizing all cases, we obtain the total probability of successful teleportation as $8|bdf|^2$. For the maximally entangled pairs, $|a| = |b| = |c| = |d| = |e| = |f| = \dfrac{1}{\sqrt{2}}$, the total probability reaches one.

As the most general pure state, an arbitrary three-particle state includes all kinds of three-particle states as special cases, no matter whether they are entangled. For instance, if $\lambda_0 \neq 0$, $\lambda_i = 0$ (i=1,2,3,4,5,6,7), $|\psi\rangle_{123} = \lambda_0|001\rangle_{123}$ is the product state; if $\lambda_3 = \lambda_6 = \dfrac{1}{\sqrt{2}}$, $\lambda_i = 0$ (i=0,1,2,4,5,7), $|\psi\rangle_{123} = \dfrac{1}{\sqrt{2}}|0\rangle_1(|00\rangle_{23} + |11\rangle_{23})$ is bipartite entanglement; if $\lambda_3 = \lambda_7 = \dfrac{1}{\sqrt{2}}$, $\lambda_i = 0$ (i=0,1,2,4,5,6), $|\psi\rangle_{123} = \dfrac{1}{\sqrt{2}}(|000\rangle_{123} + |111\rangle_{123})$ is the standard GHZ state; and if $\lambda_0 = \lambda_1 = \lambda_2 = \dfrac{1}{\sqrt{3}}$, $\lambda_i = 0$ (i=3,4,5,6,7), $|\psi\rangle_{123} = \dfrac{1}{\sqrt{3}}(|001\rangle_{123} + |010\rangle_{123} + |100\rangle_{123})$ is the standard W state. Note that states belonging to the GHZ class and W class cannot be transformed into each other by local operations and classical communication. In particular, the GHZ state can be regarded as the maximally entangled state of three qubits. However, its entanglement properties are very fragile under particle losses. In contrast, the W state retains a maximal amount of bipartite entanglement when any one of the three qubits is traced out.[16]

In summary, two different probabilistic types of teleportation of an arbitrary three-particle state via two different quantum channels are proposed in this paper. We show that, for such non-maximally entangled quantum channels, there is still a certain probability of successful teleportation if a receiver adopts some appropriate unitary transformations. Some specific unitary transformations are provided in detail. The probability of success is determined by the smaller coefficients of the entangled states that are used as quantum channels. The success probability of the first scheme is greater than that of the second scheme, and the first costs fewer bits of classical communication than the second. But because two-particle entanglement is more easily generated than three-particle entanglement, the second scheme may be easier to realize experimentally.

Finally, we indicate that the second scheme can be generalized to the teleportation of an arbitrary and unknown N-particle state.

References

[1] Bennett C H *et al* 1993 *Phys. Rev. Lett.* **70** 1895

[2] Bouwmeester D *et al* 1997 *Nature* **390** 575

[3] Boschi D *et al* 1998 *Phys. Rev. Lett.* **80** 1121

[4] Davidovich L *et al* 1994 *Phys. Rev.* A **50** R895

[5] Cirac J I *et al* 1994 *Phys. Rev.* A **50** R4441
[6] Song K H and Guo G C 2002 *Chin. Phys.* **11** 218
[7] Moussa M H Y 1996 *Phys. Rev.* A **54** 4661
[8] Zheng S B 1999 *Opt. Commun.* **167** 111
[9] Bandyopadhyay S 2000 *Phys. Rev.* A **62** 012308
[10] Lin X 2001 *Acta Phys. Sin.* **50** 686 (in Chinese)
[11] Xu X M *et al* 1999 *Acta Phys. Sin.* **48** 2154 (in Chinese)
[12] Gu Y J, Zheng Y Z and Guo G C 2001 *Chin. Phys. Lett.* **18** 1543
[13] Ye L, Yao C M and Guo G C 2001 *Chin. Phys.* **10** 1001
[14] Yang C P and Guo G C 1999 *Chin. Phys. Lett.* **16** 628
[15] Lu H 2001 *Chin. Phys. Lett.* **18** 1004
[16] Cirac J I *et al* 2000 *Phys. Rev.* A **62** 062314
[17] Li W L, Li C F and Guo G C 2000 *Phys. Rev.* A **61** 034301
[18] Clauser J F *et al* 1969 *Phys. Rev. Lett.* **23** 880
[19] Zhang C W *et al* 2000 *Phys. Rev.* A **61** 062310
[20] Monroe C *et al* 1995 *Phys. Rev. Lett.* **75** 4714