# ABSTRACT: Teleportation with mode entanglement of a single massive particle

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Entanglement is a powerful basis independent correlation between two or more quanta that can be used for quantum communication and quantum information processing. In order to correctly define (and physically access) entanglement, the Hilbert space of the composite system must have a tensor product structure. However, for indistinguishable particles, i.e. identical particles whose de Broglie wavelengths overlap, the Hilbert space is a projection on to the symmetric or anti-symmetric subspaces depending on the particle statistics. Thus, entanglement of indistinguishable particles can no longer be defined in the same manner as entanglement between distinct quantum objects [1].

While one can unambiguously assign identities to indistinguishable particles (and thus recover the tensor product Hilbert space structure) by incorporating a set of detectors into the definition of entanglement [2], another way to obtain distinguishable subsystems is to describe the system in a field theoretic manner. Here one defines a complete set of field modes and counts the number of excitations in each. Entanglement then exists between modes with the particle number of a mode providing the entangling degree of freedom.

The existence of such entanglement implies that a single particle can be entangled. Single photon entanglement has been extensively studied, see e.g. [3–5] and experimentally verified [6]. However, the true nature of mode entanglement of massive particles is still under debate. This is due to the fact that, unlike photons, massive particles cannot be created or destroyed. Typically, to confirm entanglement one must show that correlations exist in more than one basis, which for mode entanglement would imply the creation or destruction of particles; yet this is forbidden for an isolated system due to a particle number superselection rule [7].

In my talk, I will discuss how one can perform quantum teleportation [8] with the mode entanglement of a single massive particle, despite the superselection rule. To locally overcome the superselection rule, a Bose-Einstein condensate is used as a particle reservoir in a similar manner to [9]. I will outline how to perform the different steps in the teleportation scheme, namely (i) the preparation of an unknown state of a spatial mode and the initial bi-mode entangled state; (ii) the Bell state measurement on two spatial modes and (iii) the final, recovering operation. We will find that reliable teleportation is only possible half of the time, but suggest how this could be extended to the full protocol. This contrasts with another recent paper [10], which considers whether the mode entanglement of a single massive particle could be used for dense coding. There it was shown that the full quantum channel capacity was achievable within the confines of a similar set up.

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