EFFICIENT BELL STATE MEASUREMENT WITH TIME-BIN QUBITS

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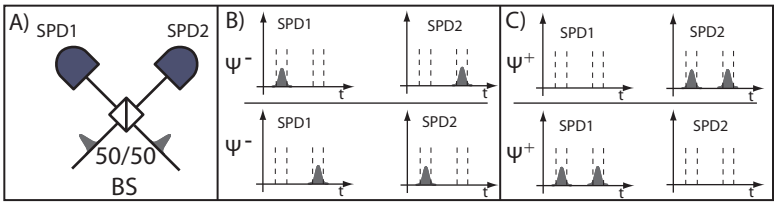
Bell state measurements (BSMs) play a key role in quantum repeaters [1] and in measurement-device-independent quantum key distribution (MDI-QKD) [2, 3]. Time-bin qubits [3] are often used as they are relatively easy to implement. However, technological challenges arise when performing BSMs with time-bin qubits, which requires superposing two qubits on a 50/50 beamsplitter (BS), and recording time-resolved detections in subsequent single photon detectors (SPDs), as shown in figure A. A projection onto the $|\psi^-\rangle$ state is characterized by one of the two detectors registering an event in the early time-bin and the second detector registering an event in the late time-bin, see figure B. On the other hand, a projection onto $|\psi^+\rangle$ happens when one of the detectors registers an event in both the early and late time-bins, see figure C. Due to the long recovery times of most single photon detectors (on the order of a few μs), typical implementations only measure projections onto the $|\psi^-\rangle$ state. This technological obstacle translates into a success probability of the BSM of only 25%, a factor of two below the maximum allowed by linear optics. In addition the BSM efficiency scales as η^2 where η labels the detection efficiency, which, assuming a typical value for InGaAs APDs of 15%, yields $\eta^2 \approx 0.02$. Here we present the first implementation of a BSM using time-bin qubits with projections onto the $|\psi^+\rangle$ state. Various qubit states are generated using weak laser pulses with a mean photon number of μ=0.2. The measurement is performed with state-of-the-art superconducting nanowire single-photon detectors (SNSPDs) with detection efficiencies of ≈80%, low dark count rates, and recovery times <100ns [4]. We have measured the quantum bit error rates (QBER) for qubits prepared in the z-basis ($|0\rangle$, $|1\rangle$) and the x-basis ($|\pm\rangle=(1/\sqrt{2})(|0\rangle \pm |1\rangle)$) conditioned on Bell state projections onto $|\psi^+\rangle$ after having transmitted each qubit over 20 kms of spooled fiber. The results given in the following table clearly show the possibility for BSMs using time-bin qubits with projections onto the $|\psi^+\rangle$ state. If both states, $|\psi^-\rangle$ and $|\psi^+\rangle$, are measured, the BSM efficiency is improved by roughly a factor of 60 compared to BSMs using standard InGaAs APDs. This efficiency improvement has a direct positive impact on quantum repeaters and MDI-QKD implementations.



μ = 0.2		$\|\psi^+\rangle$ projection	
		z-basis	**x-basis**
QBER (%)	theory	0	25
	experiment	4.9%	28.8%

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