

Erratum: Cavity-assisted controlled phase-flip gates [Phys. Rev. A **102**, 013703 (2020)]

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We have identified an error in the analytical calculation of the fidelity for the photon scattering gate discussed in Sec. II A of the paper. In this scheme, the gate is heralded upon detection of the scattered photon from the qubit-cavity system. However, in the paper, the reported fidelity was calculated for the case where the photon is scattered but not detected. Consequently, we neglected the renormalization factor of the final state after heralding the gate by postselecting on the successful detection of the scattered photon. This factor depends on the cavity cooperativity and leads to the fidelity scaling as $1 - 11/32C^2$ rather than the originally stated expression $1 - 5/4C$. In this Erratum, we provide the corrected fidelity expressions, using the paper's equation numbering.

As a result of correcting this error, Eq. (1) should be replaced with

$$F_{\text{gate}} = 1 - \frac{11}{32C^2} - \frac{\delta_p^2 + \sigma_p^2}{8\gamma^2 C^2} (11 - 20\alpha^2 + 12\alpha^4) - \frac{41(\delta_{\epsilon_A}^2 + \delta_{\epsilon_B}^2) - 38\delta_{\epsilon_A}\delta_{\epsilon_B}}{32\gamma^2 C^2} - \frac{(-11 + 10\alpha^2)(\delta_{\epsilon_A} + \delta_{\epsilon_B})\delta_p}{8\gamma^2 C^2} - \Gamma T, \quad (1)$$

which corresponds to the heralded fidelity of the scattering gate. Here $\alpha = 2g/\kappa$. In addition, Eq. (B8) should be updated to

$$F_{\text{max}} = \frac{-s_{\downarrow\downarrow} + s_{\downarrow\uparrow} + s_{\uparrow\downarrow} + s_{\uparrow\uparrow}}{2\sqrt{s_{\downarrow\downarrow}^2 + s_{\downarrow\uparrow}^2 + s_{\uparrow\downarrow}^2 + s_{\uparrow\uparrow}^2}} \simeq 1 - \frac{11}{32C^2}. \quad (B8)$$

As a result of this correction, we have the following.

Figures 2, 7, and 8 have been updated as shown below. These revisions show that the fidelity of the photon scattering gate is higher than originally estimated, further supporting the conclusion that this gate is especially well suited for applications where performing a high-fidelity gate is prioritized over achieving deterministic operation.

In the first paragraph of Sec. III A, $1 - 5/4C$ should be replaced with $1 - 11/32C^2$. More precisely, in the scenario discussed in the published version, the $1/C$ scaling dominated over secondary sources of error arising from detuning and dephasing. However, with the improved $1/C^2$ fundamental maximum scaling in the heralded scenario described above, these secondary sources of error now almost always dominate. As such, the improvements in fidelity are limited in practice. This is illustrated in the corrected Fig. 2(a) below, where the upper bound, now set by $1 - 11/32C^2$, gives seven 9's and is far above the plotted regime. It is also illustrated in the corrected Fig. 8(a) below, where the two cases only begin to diverge with a gate fidelity exceeding 0.999, corresponding to very low dephasing rates of $10^{-3}\gamma$.

These updates do not affect the main conclusions of the paper, namely, (i) the scattering scheme is well suited for systems with an integrated design and when achieving high-fidelity gates is prioritized over deterministic operation and (ii) it may also be of interest in systems with lower cavity cooperativity, as it achieves the highest fidelity scaling with cavity cooperativity compared to both the Raman and simple exchange schemes. In addition, all results in the published version [including Eqs. (1) and (B8)] remain valid for the scattering gate in the scenario where it is certain that a photon entered the cavity but uncertain whether it was detected after scattering. It should be noted that to calculate the unheralded fidelity (that is, the case where we have no knowledge of whether a photon interacted with the system) one must still multiply the fidelity given in Eq. (1) of the published version by the probability that a photon entered the cavity.

We thank Sumit Goswami for bringing the error to our attention.

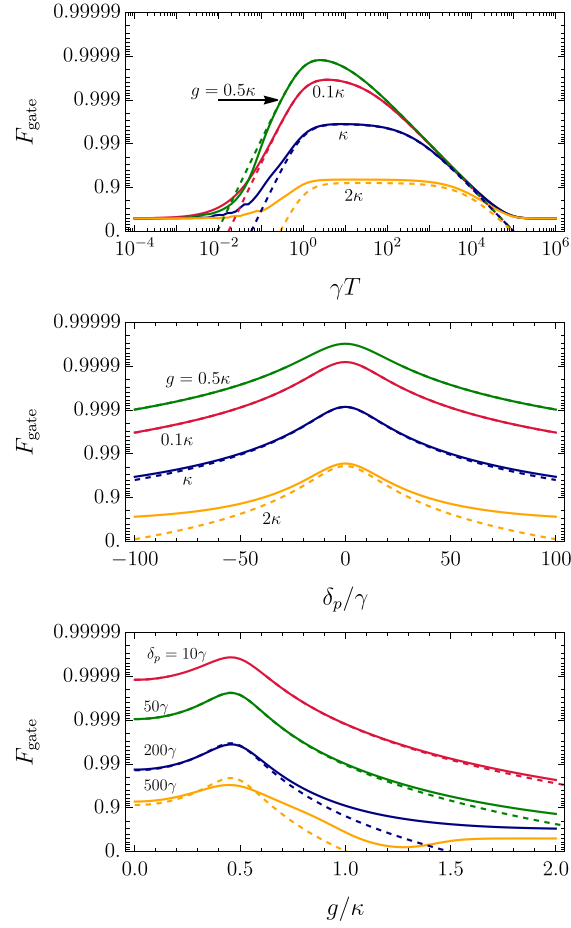


FIG. 2. Fidelity of the photon scattering phase gate as a function of (a) the gate time T , (b) the photon-cavity detuning δ_p for a given cavity regime, and (c) the cavity regime for a given photon-cavity detuning. Here we set the cavity cooperativity to $C = 2000$, quantum system detunings to $\delta_{\epsilon_A} = \delta_{\epsilon_B} = 0$, the effective dephasing to $\Gamma/\gamma = 10^{-5}$, and (a) $\delta_p = 30\gamma$ and (b) and (c) $T = 2/\gamma$. The ratio of the cavity coupling rate g to the cavity dissipation rate κ gives the regime of operation with $g/\kappa \ll 1$ and $g/\kappa \gg 1$ indicating the bad-cavity and strong-coupling regimes, respectively. The solid lines show the numerical solution without expanding around small $\delta_p/\gamma C$, $\sigma_p/\gamma C$, and large C . The dashed lines correspond to the analytic approximation given by Eq. (1). For the numerical simulation, we assume that the effective decoherence rate Γ exponentially degrades the coherence of the reduced spin density matrix as opposed to using the linear correction as in the analytic approximation.

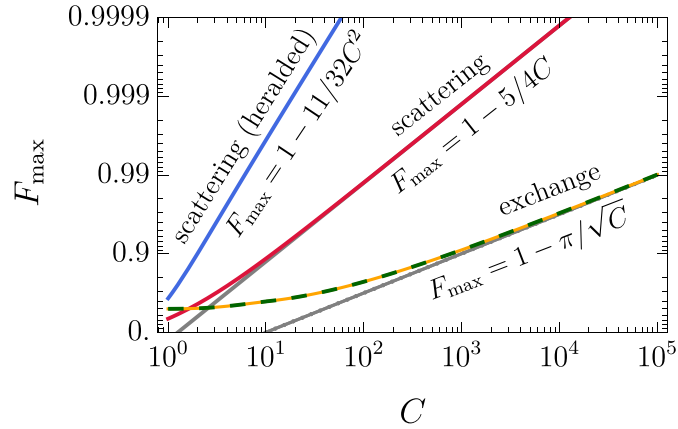


FIG. 7. Cooperativity-limited fidelity F_{max} for phase gates based on photon scattering and virtual photon exchange. The simple photon exchange (orange line) and Raman photon exchange (green dashed line) have the same F_{max} values. The straight gray lines represent the F_{max} scaling in the limit of large C . These first-order approximations underestimate the maximum fidelity when the cooperativity is low, but still give a good estimate when the fidelity is larger than 0.8. The scattering curve (red) shows the gate fidelity scaling when the photon is scattered but not detected, while the scattering (heralded) curve (blue) shows the fidelity after postselecting on the successful detection of the scattered photon.

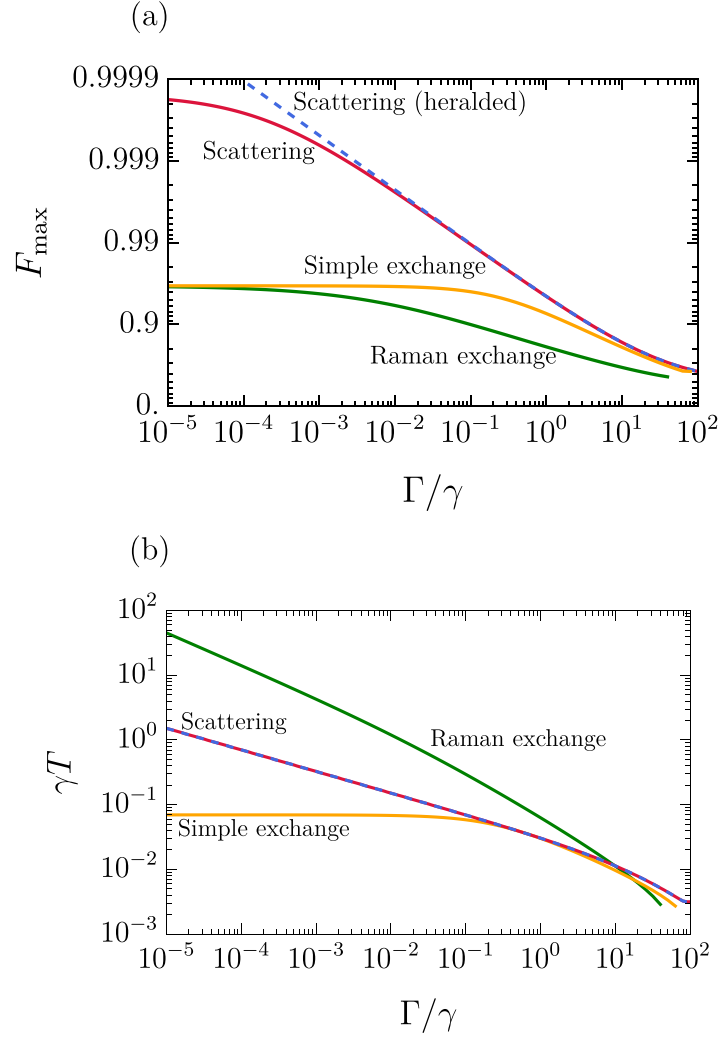


FIG. 8. (a) Maximum fidelity $F_{\max}$ as a function of effective qubit decoherence rate Γ in the bad-cavity regime ($g/\kappa = 10^{-1}$) with cooperativity $C = 8000$. The red curve denotes the scattering scheme with photons scattered but not detected; the blue dashed curve, the scattering scheme with heralding (postselecting on successful photon detection); the orange curve, the simple virtual photon exchange scheme; and the green curve, the Raman virtual photon exchange scheme. (b) Gate time corresponding to the maximum fidelity in (a), which is independent of whether the scattered photon is detected.