

Erratum: Nonclassical coincidences of atomic and mechanical excitations **[Phys. Rev. Research 6, 033228 (2024)]**

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In the original manuscript, we incompletely used only *uncorrelated* classical bipartite states to find the upper bound for the classical coincidences [Eq. (9) of the original manuscript]. That is, we used the states of the form

$$\hat{\rho}_{AM}^{\text{unc}} = \int P_A(\alpha) \times P_M(\beta) |\alpha\rangle\langle\alpha| \otimes |\beta\rangle\langle\beta| d^2\alpha d^2\beta, \quad (1)$$

where P_i are the Glauber-Sudarshan P functions of each individual mode, satisfying the properties of ordinary probability distributions. For the full set of all classical bipartite states, we should use instead the states of the form

$$\hat{\rho}_{AM}^c = \int P_{AM}(\alpha, \beta) |\alpha\rangle\langle\alpha| \otimes |\beta\rangle\langle\beta| d^2\alpha d^2\beta, \quad (2)$$

where the two-mode P function may not factorize to a product of two single-mode P functions. The set of states $\hat{\rho}_{AM}^c$ contains, among others, all the states of the form $\hat{\rho}_{AM}^{\text{unc}}$ and also all *correlated* classical states. Hence, the optimization over the broader class of states $\hat{\rho}_{AM}^c$ yields in some cases a higher threshold $F_{11}(\hat{\rho})$ for the $p_{11} = \langle 11 | \hat{\rho} | 11 \rangle$ element of $\hat{\rho}$. The updated threshold must be computed numerically by the following optimization:

$$F_{11}(p_{0A}, p_{0M}) = \max_{\hat{\rho}_{AM}^c} \langle 11 | \hat{\rho}_{AM}^c | 11 \rangle, \quad (3)$$

$$\text{s.t. } \text{Tr}_M \langle 0_A | \hat{\rho}_{AM}^c | 0_A \rangle = p_{0A}, \quad \text{Tr}_A \langle 0_M | \hat{\rho}_{AM}^c | 0_M \rangle = p_{0M}. \quad (4)$$

The findings of our paper thus have to include optimization of the nonclassicality witness Δ [defined in Eq. (10)] featuring the correct values of the threshold F_{11} . The previously used threshold for uncorrelated classical states can still be used as a preliminary one for evaluation of the atom-mechanical states.

The results of the corrected maximization of the nonclassical coincidence probability for the atom-mechanical system are provided in Fig. 1 [replaces Fig. 2 from the original manuscript]. The results for atom-optical and optomechanical systems are provided in Fig. 2 [replaces Fig. 3 from the original manuscript]. A close comparison reveals that the possible advantage Δ of the observable coincidences over the corrected threshold (excluding all classical states) reaches the values that do not differ much from the advantage over the uncorrelated classical states. As the updated figures illustrate, in state-of-the-art atom-optomechanical systems, it is possible to overcome as well the completed threshold F_{11} . The conclusions of our paper thus remain valid. The results are stronger, as also all correlated classical states are excluded. With the parameters of the existing experiments, or with the parameters that are within reach, it is possible to produce quantum states of atom-mechanical systems that exhibit coincidences of excitations beyond *all* classical states.

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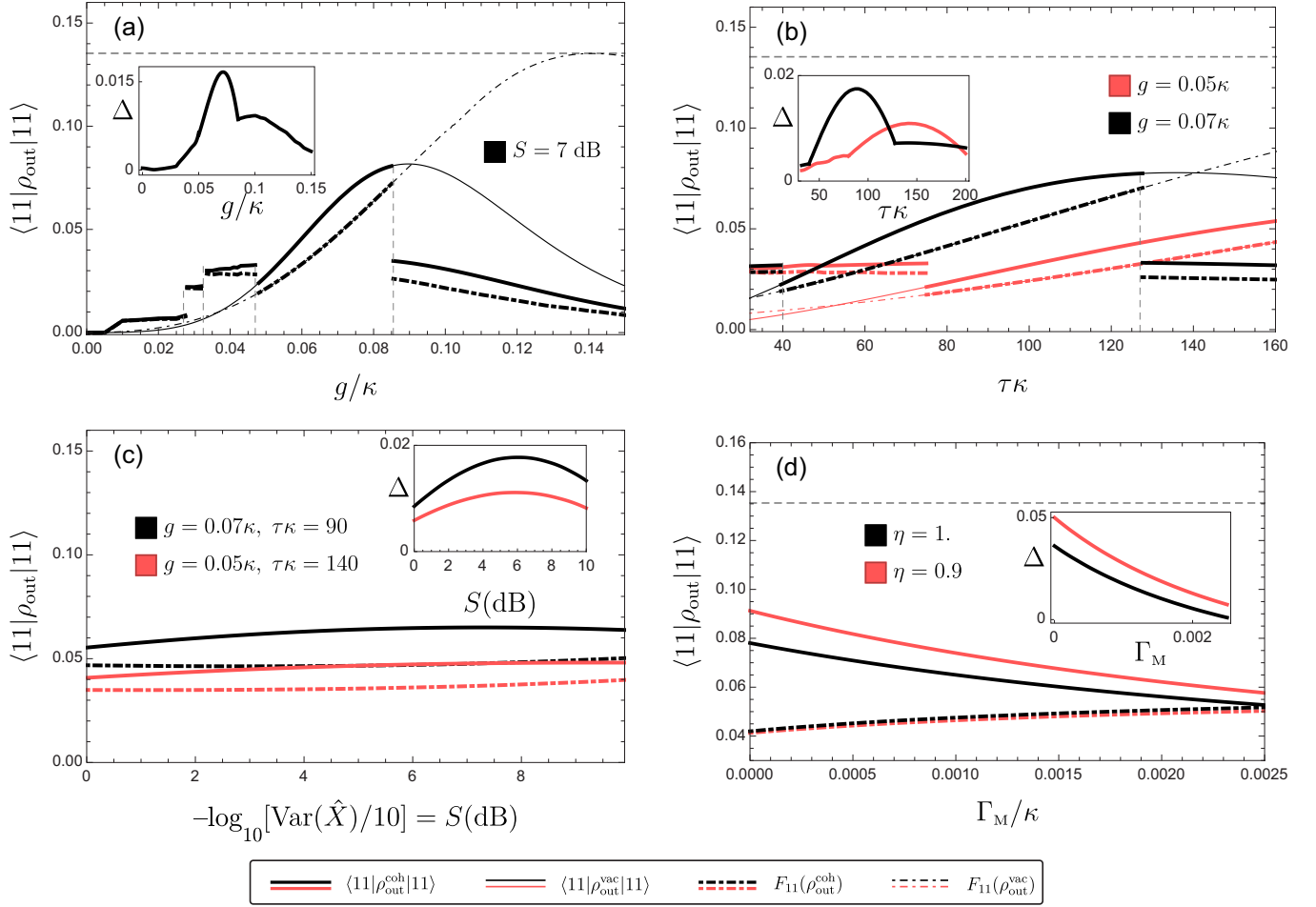


FIG. 1. Nonclassical coincidence probability $\langle 11 | \rho_{\text{out}} | 11 \rangle$ at the output of the atom-mechanical QND gate given coherent states at the input. Matrix elements $\langle 11 | \rho_{\text{out}} | 11 \rangle$ (solid curves) and nonclassicality thresholds $F_{11}(\rho_{\text{out}})$ (dot-dashed curves) for the state ρ_{out} at the output of atom-mechanical QND gate with coherent states at the input. Thick curves are calculated using the vector of means of ρ^{coh} providing the maximal advantage Δ [defined in Eq. (10)]. Thin curves correspond to the matrix elements of the output state of the gate with the vacuum input: (a) dependence on the coupling strength for the squeezing of 7 dB, assuming $g = g_A = g_M$; (b) dependence on the pulse duration τ for different coupling strengths (black for $g = 0.07\kappa$, red for $g = 0.05\kappa$). In panels (a) and (b), thin vertical lines indicate the value of the arguments at which the optimal family of the input states changes; (c) dependence on the squeezing (black for $g = 0.05\kappa$, $\tau\kappa = 140$, red for $g = 0.07\kappa$, $\tau\kappa = 90$); and (d) dependence on the rethermalization rate for different efficiencies for $g = 0.07\kappa$. The inset shows dependence on the efficiency. Even for low efficiency and high rethermalization, it is possible to find an input state providing positive advantage Δ . Numerical parameters, where not specified otherwise, are $\tau = 90/\kappa$, $\eta = 0.9$, $\Gamma_M = 10^{-3}\kappa$, and $S = 7$ dB.

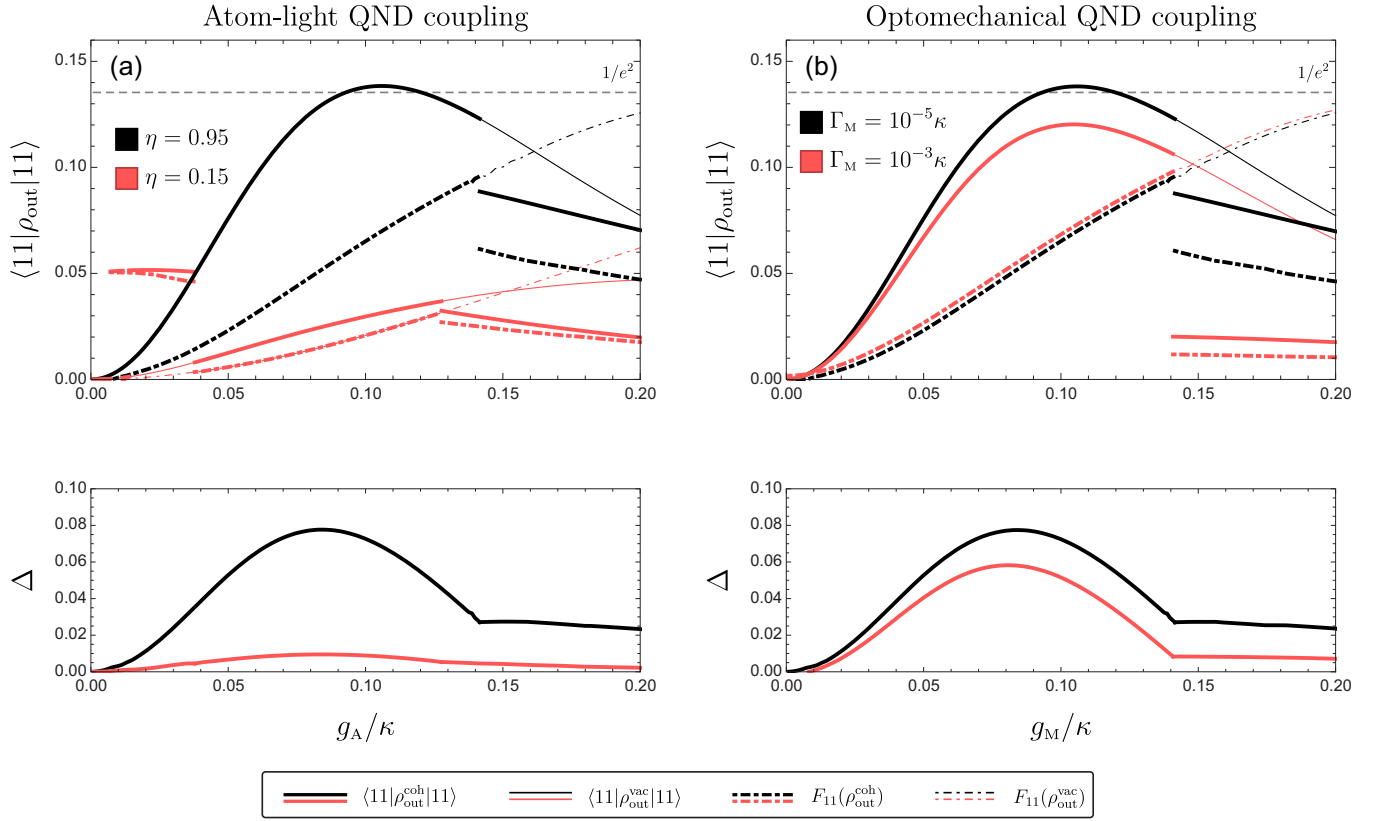


FIG. 2. Nonclassical coincidence probability $\langle 11 | \rho_{\text{out}} | 11 \rangle$ at the output of a QND interaction in (a) atom-light system and (b) optomechanical system. Matrix elements $\langle 11 | \rho_{\text{out}} | 11 \rangle$ at the output (solid curves) and corresponding nonclassicality thresholds $F_{11}(\rho_{\text{out}})$ (dot-dashed curves) given coherent states at the input. Thick curves correspond to the input state that provides maximal advantage Δ [defined in Eq. (10)] at the output. Thin curves correspond to vacuum input. The dashed gray line is the output classical threshold ($1/e^2$). The numerical parameters are (a) pulse duration $\tau = 90/\kappa$ and efficiencies $\eta = 0.95$ for black and $\eta = 0.15$ for red, and (b) $\tau = 90/\kappa$, $\eta = 0.95$, and rethermalization rates $\Gamma_M = 10^{-5}\kappa$ for black and $\Gamma_M = 10^{-2}\kappa$ for red.