Kuhn, Hennrich, and Rempe Reply: A recent Comment [1] addresses the question of whether a deterministic and intrinsically reversible single-photon source has been demonstrated in Ref. [2]. The author of [1] admits that [2] is an advance towards these goals, but he has four objections.

First, reversibility has not been demonstrated. This is no objection, since there is no such claim in Ref. [2]. We point out only that the Raman process used for photon generation is intrinsically reversible. This has been shown, in fact, by the author of [1] in [3].

Second, the stochastic trajectories of the atoms lead to phase fluctuations. These are neglected in [2], since the velocity of the atoms along the cavity axis is restricted to ± 5 mm/s, which leads to a phase jitter below $\pm\pi/40$ for a 2 μs long pulse. This has a negligible influence on the Raman process. Preserving a fixed phase relation between several atoms at different locations requires technical efforts which are beyond the scope of [2].

Third, it is claimed that the fluorescence from an ensemble of continuously pumped two-state atoms (Fig. 1 in [1]) reproduces the essential characteristics of our experiment. This comparison is inadequate, since $g^{(2)}(\tau) \geq 1$ is due to out-of-phase Rabi oscillations of different atoms. In [2], however, the emission probabilities of all atoms oscillate in phase because the pump laser operates periodically. This leads to a periodic modulation of $g^2(\tau)$. In Fig. 4 in [2], this contribution is hidden in the noise. To illustrate its effect, it is necessary to look at a measurement with increased atom flux [4]: Fig. 1 shows the oscillatory different-atom contribution as a hatched area, and a pedestal involving background counts as a cross-hatched area. Note that the oscillatory contribution has a time-independent amplitude. It follows that $g^{(2)}(0)$ is mainly ($> 60\%$) determined by different atoms that emit simultaneously. As the oscillatory contribution is not visible in Fig. 4 of [2], many-atom emissions can be neglected there. The fact that $g^{(2)}(0)$ does not exceed the background contribution, together with the large correlation peaks at $\tau = \pm 4$ μs, proves that a single atom emits at most a single photon per pulse. Note that for a periodically driven Poissonian emitter, $g^{(2)}(0)$ would be at least as large as all other correlation peaks.

Fourth, the author of [1] says that the measured correlation function does not support the deterministic generation of single photons. It is argued that, without *a priori* knowledge about the presence of an atom in the cavity, the Poissonian atom statistics is simply mapped to the photon statistics. This point has already been addressed in [2], where we "emphasize that the detection of a first photon signals the presence of an atom… photons emitted from this atom during subsequent pump pulses dominate the photon statistics and give rise to antibunching." However, a quantitative analysis was not presented in [2], since no established procedure exists to analyze a nonstationary nonclassical light source. In our experiment, a possible protocol is to interpret every photon detected during a pump pulse as a flag indicating the presence of an atom and then to restrict the statistical analysis to the light emitted during the adjacent pump intervals. These constitute a set of N pump intervals conditioned on the presence of atoms. The events in this set form a new data stream which is used to calculate the correlation function, $g^{(2)}(\Delta i) = \sum_{i=1}^{N} E_1(i)E_2(i + \Delta i)/(N\bar{E}_1\bar{E}_2)$, where $E_{1,2}(i)$ are the numbers of events observed by detectors $D_{1,2}$ during the ith pulse in the new data stream. Application of this straightforward analysis to the original data of [2] yields $g^{(2)}(\Delta i = 0) = 0.25(11)$ and $g^{(2)}(\Delta i \neq 0) = 1.00(22)$. This demonstrates that the photon statistics conditioned on the presence of atoms is sub-Poissonian, as can be expected from the antibunching effect shown in [2].

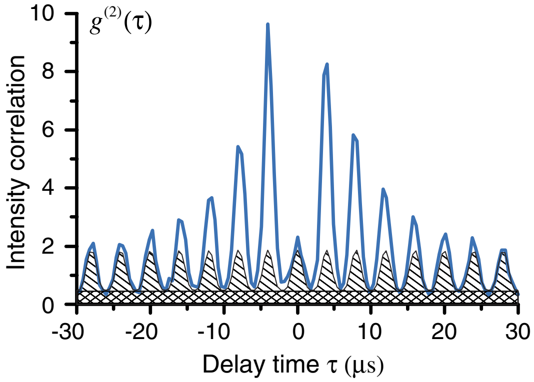

FIG. 1 (color online). Intensity correlation function, $g^{(2)}(\tau)$, for a flux of 10 atoms/ms. The hatched and cross-hatched areas indicate, respectively, the different-atom and the background-noise contributions.

Axel Kuhn, Markus Hennrich, and Gerhard Rempe
Max-Planck-Institut für Quantenoptik
Hans-Kopfermann-Strasse 1
85748 Garching, Germany

Received 1 November 2002; published 17 June 2003
DOI: 10.1103/PhysRevLett.90.249802
PACS numbers: 03.67.Hk, 03.67.–a, 32.80.Bx, 42.65.Dr

[1] H. J. Kimble, preceding Comment, Phys. Rev. Lett. **90**, 249801 (2003).
[2] A. Kuhn *et al.*, Phys. Rev. Lett. **89**, 067901 (2002).
[3] J. I. Cirac *et al.*, Phys. Rev. Lett. **78**, 3221 (1997).
[4] A. Kuhn *et al.*, in *Quantum Information Processing*, edited by G. Leuchs and T. Beth (Wiley-VCH, Weinheim, 2003), pp. 182–195.

0031-9007/03/90(24)/249802(1)$20.00