

Observation of atom pairs in spontaneous four wave mixing of two colliding Bose-Einstein Condensates: supplementary information

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Here we give some additional technical details concerning the experiment for interested readers.

Raman laser beams: Figure 1 shows the approximate geometry of the Raman laser beams which generate the two colliding condensates. More precisely, an approximately vertical beam propagates in the direction defined by $\mathbf{e}_1 = \cos\theta\mathbf{e}_z + \sin\theta\mathbf{e}_y$ with $\theta \approx 7^\circ$, and where \mathbf{e} represents a unit vector. This beam is π -polarized (parallel to the x -axis). A second, horizontal beam propagates in the direction defined by $\mathbf{e}_2 = \cos\phi\mathbf{e}_x + \sin\phi\mathbf{e}_y$ with $\phi \approx 5^\circ$. The polarization is circular and corresponds nearly to σ^- . Perfect σ^- polarization with respect to the x axis is not possible unless $\phi = 0$. The laser beams are blue-detuned by 400 MHz from the $2^3S_1 - 2^3P_0$ transition (wavelength 1083 nm) and have a relative detuning of about 700 kHz to match the Raman resonance between the two Zeeman sublevels. The horizontal beam is retro-reflected. The intensity of laser L_1 is 100 mW/cm² whereas the intensities of laser L_2 and L'_2 are 50 mW/cm². The waist of these beams is 2.8 mm so that the intensity over the condensate is approximately constant.

The Raman detuning, 700 kHz is not very large compared to the Fourier limited width of the pulses. If in addition, the polarization of one beam is not exactly π or σ , a single beam (L_1 , L_2 or L'_2) can drive a Raman transition with no momentum transfer. This is the likely mechanism for the production of the condensate III in Fig. 2. In subsequent experiments we have observed that a better polarizer for L_1 substantially reduces the number of atoms in condensate III.

Detector resolution: In earlier work, we showed that the single particle resolution was of order 300 μm corresponding to a velocity resolution of 0.1 v_{rec} . The two particle resolution is a factor of $\sqrt{2}$ larger.

Size of the condensate: In the Thomas Fermi limit and for 3×10^4 atoms the chemical potential is $\mu/h = 3.5$ kHz. The Thomas-Fermi radii R are 90 μm and 3.5 μm in the axial and radial directions. Since the number of atoms is not large, the Thomas Fermi approximation is questionable. To go beyond that approximation we calculate the BEC profiles numerically, by solving the Gross-Pitaevskii equation. The deduced profile only differs from the Thomas-Fermi one by the appearance of wings in the profile along the radial axes. This makes the velocity distribution of the condensates slightly different. Our numerically estimated rms ve-

locities given in the main text are about $2\hbar/mR$.

In addition to governing the width of the correlation functions, the quantity v^{rms} should determine the thickness of the scattering sphere. We observe an rms width of 0.08 v_{rec} averaged over the detected part of the sphere, close to the value of v_{yz}^{rms} (0.091 v_{rec}). Along the x direction the thickness of the sphere should be smaller corresponding to v_x^{rms} (0.0044 v_{rec}), but the presence of the unscattered condensates renders that direction inaccessible. Thus the measured thickness of the sphere corroborates our estimate of the size and velocity distribution of the source.

Definition of $g^{(2)}(\mathbf{V})$: Our histogramming procedure to find the correlation function for back to back pairs corresponds to first calculating the averaged unnormalized correlation function $\overline{G^{(2)}}$:

$$\overline{G^{(2)}}(\mathbf{V}) = \int d^3\mathbf{V}_1 G^{(2)}(\mathbf{V}_1, -\mathbf{V}_1 + \mathbf{V}) \quad (1)$$

For collinear pairs we compute

$$\overline{G^{(2)}}(\mathbf{V}') = \int d^3\mathbf{V}_1 G^{(2)}(\mathbf{V}_1, \mathbf{V}_1 + \mathbf{V}') \quad (2)$$

These results are normalized as explained in the main text to obtain $g^{(2)}(\mathbf{V})$ and $g^{(2)}(\mathbf{V}')$.

Comment on Fig. 3: The figure plots a projected and averaged correlation function. This procedure tends to reduce the peak heights. The plotted curve in each panel is a Gaussian with a width determined by the 3D fit and a height determined by fitting the height of the averaged and projected data.

In the second panel of Fig. 3 a (the y axis), the points lie systematically above the line. This may be due to the fact that because of our elimination of the areas around the condensates, most of the data for the y direction comes from points close to the $y - z$ plane. This means that the main contribution to the correlation data along y comes from different points along the radius of the sphere. Since the thickness of the sphere is of similar shape and size as the correlation function itself, the normalization has the same shape as the correlation data rendering the normalization of the wings of the curve very sensitive to noise. Thus the correlation functions along x and z give a better view of the quality of the data. The fit however makes use of all the data points at once and suffers less from this problem.