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Supplementary Materials for

Strong spin-photon coupling in silicon

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Correction: A reference (*16*) was added in the main text; references have thus been renumbered.

Materials and Methods

The device was fabricated on a Si/SiGe heterostructure grown by reduced-pressure chemical vapour on a n-type Si(100) substrate. The Si/SiGe heterostructure comprises a 900 nm thick linearly graded $Si_{1-x}Ge_x$ layer, followed by a 300 nm thick relaxed $Si_{0.7}Ge_{0.3}$ layer, a 10 nm thick strained natural Si quantum well, a 30 nm thick $Si_{0.7}Ge_{0.3}$ spacer, and a 1 nm thick Si cap. To insulate the gates used to define the quantum dots, 20 nm of Al_2O_3 was grown in the dot region with atomic-layer-deposition. Subsequently, the gates were fabricated using electron beam lithography, evaporation and a lift-off process of 25 nm of Al. The superconducting nanowire resonator, coplanar waveguide feedline and ground planes were fabricated by sputtering 14 nm thick layer of NbTiN, followed by reactive ion etching in a SF_6/He plasma. The gate oxide is removed in the superconductor region prior to reactive ion etching to reduce dielectric loss. We estimate a sheet inductance of $L_S \approx 9.1\ \mathrm{pH}/\square$ for the film.

The completed device was cooled in a dilution refrigerator with 10 mK base temperature, and 70 dB cold attenuation between room temperature and the feed line input.

Supplementary Text

Device images

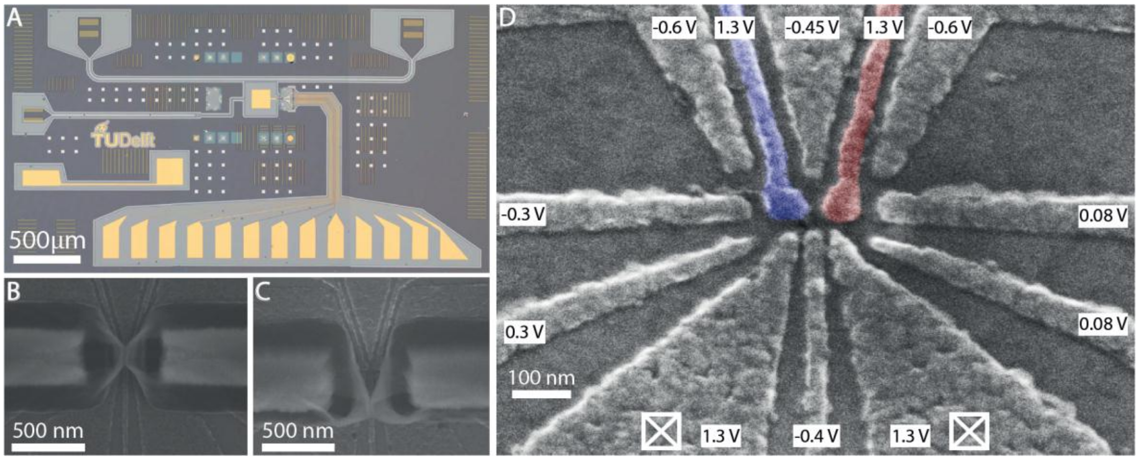

Fig. S1.

(**A**) Optical micrograph showing a microwave feed line (top), superconducting resonator (center), a double quantum dot with bond pads (right and bottom) and a line to apply a DC bias to the resonator (left). Dark grey areas are NbTiN, light grey the exposed Si surface, and yellow Au pads and lines. **(B**) Scanning electron microscope (SEM) image of a finished device with Co micromagnets on top of SiN_x. The micromagnets are 220 nm thick, 360 nm wide, and separated by 500 nm. (**C**) Angled SEM image of the device showing the position of the micromagnets with respect to the dot accumulation gates. (**D**) Image of the device with typical voltages applied to the gates the in single electron regime. The purple and red colored gates are connected to the resonator ends.

Measurement setup

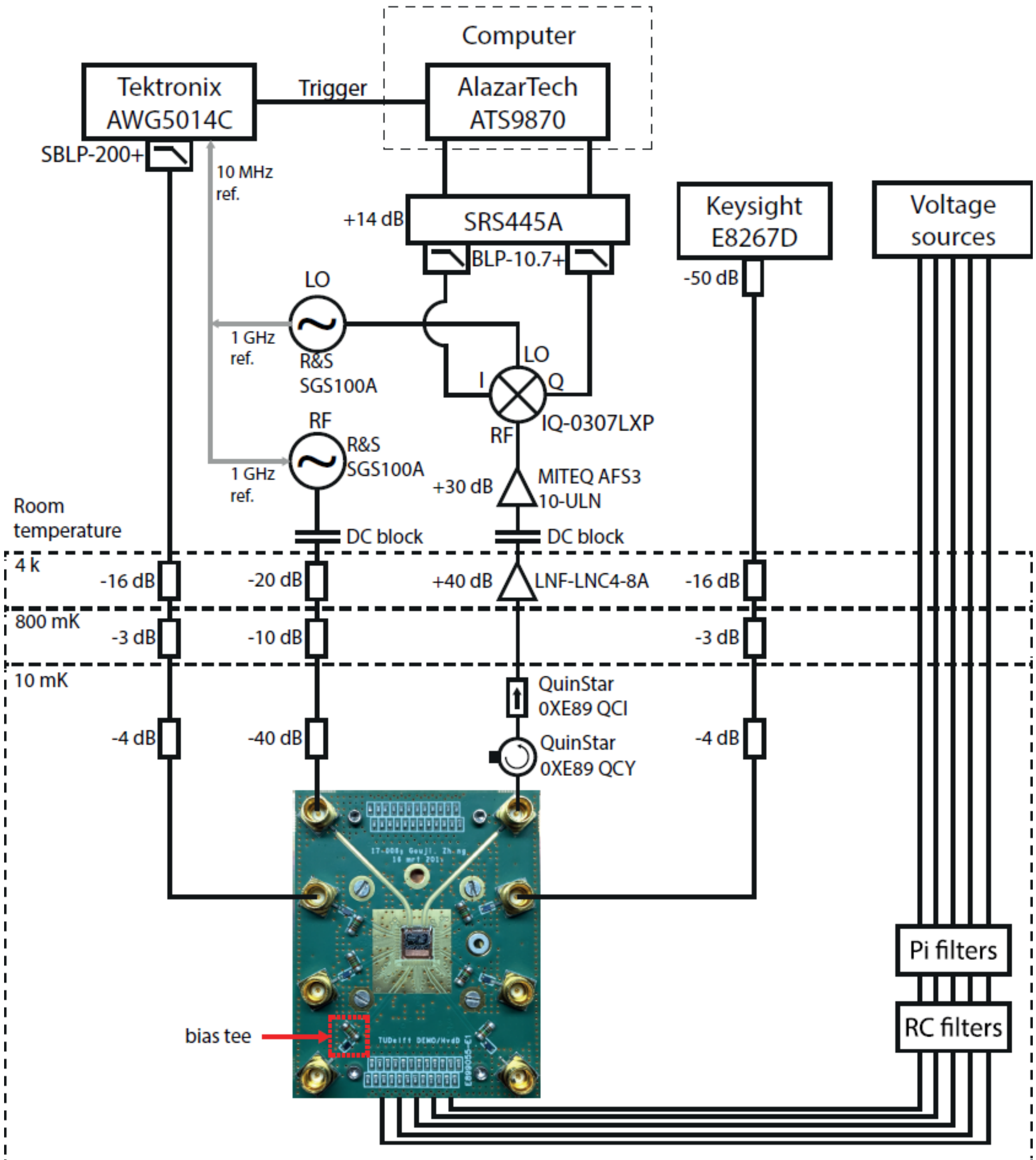

Fig. S2

Schematic of the measurement setup.

Additional structure in the avoided crossing

A small additional structure located between the two well resolved vacuum Rabi splitting peaks can be observed in Fig. 2C and Fig. 4,C and D. We note that this peak has an asymmetric behavior with respect to the external magnetic field. To eliminate the possibility that this structure is due to magnetic hysteresis effects in the Co micromagnets, we compared the feed line transmission for the spin qubit in the configuration corresponding to the avoided crossing (with $2t_c/h \approx 10.4$ GHz) when ramping up or down the magnetic field. The observed anticrossing is unchanged for both directions, as can be seen in Fig. S3. Moreover, increasing the measurement power by 20 dB did not reveal a change in this additional structure, suggesting that it is not due to stray photon population. Finally, we computed the transmission spectrum using an input-output model including the spin, charge and photon using the theory from Ref. 28. Using the measured spin qubit parameters, this theoretical result, shown in Fig. S4, did not show any feature similar to the one observed in Fig. 2C and Fig. 4, C and D. To conclude, while the origin of this small additional structure remains to be clarified, the avoided crossing of the spin qubit and the resonator responds fully as expected to changes in DQD detuning, DQD tunnel coupling, and magnetic field. Also the two-tone spectroscopy data appears not to be affected by this small feature.

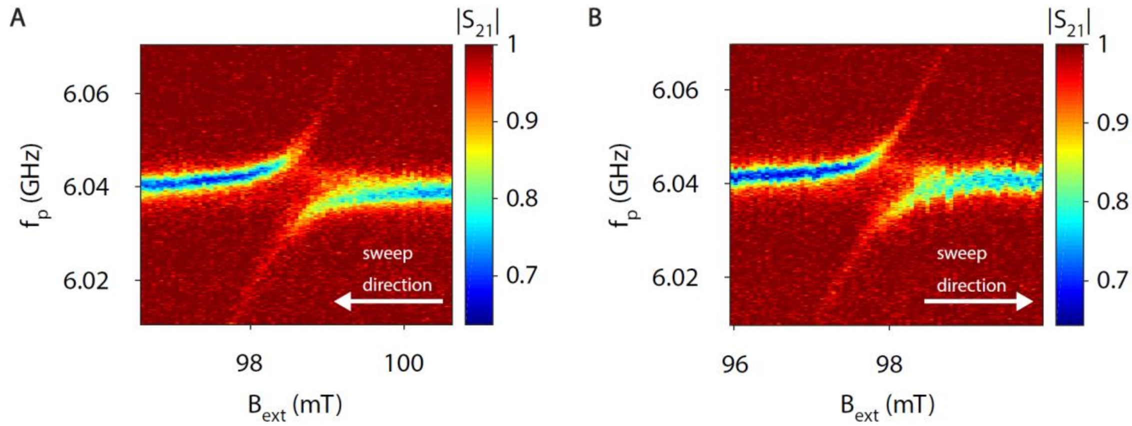

Fig. S3

(**A**) Copy of Fig. 4C in the main text where the sweep direction of B_{ext} is from high to low field. (**B**) Similar data to (A), but with B_{ext} swept in the opposite direction.

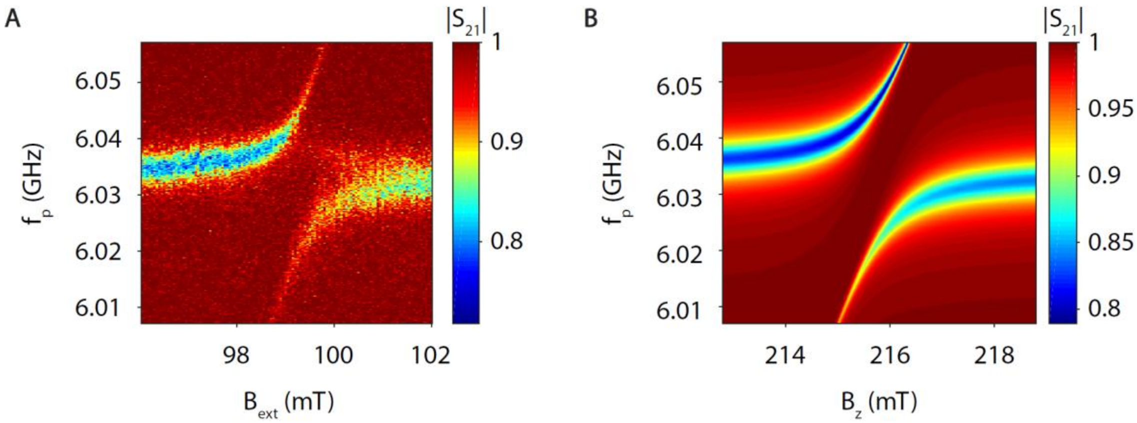

Fig. S4

(**A**) Copy of Fig. 2C in the main text. (**B**) Simulation of the transmission using the following parameters: $\varepsilon = 0$, $2t_c/h = 8.7$ GHz, $g_c/2\pi = 210$ MHz, $\Delta B_x = 23$ mT, $\gamma_c/2\pi = 52$ MHz, $f_r = 6.0507$ GHz, $\kappa_r/2\pi = 2.7$ MHz, $\kappa_{\text{int}}/2\pi = 1.46$ MHz. Here, $B_z = B_{\text{ext}} + B_{z,mm}$, with $B_{z,mm}$ the stray field of the micromagnets in the direction of the external magnetic field.

Bare cavity resonance

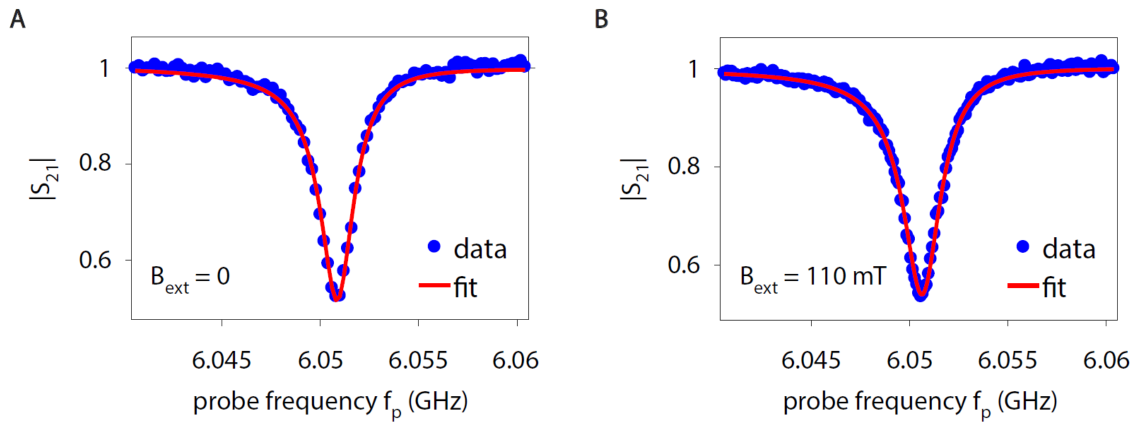

Fig. S5

(**A**) Cavity resonance before the formation of the DQD and in the absence of an external magnetic field. (**B**) Similar data to (A), but after the formation of the DQD with a single electron confined in one of the dots and $B_{\mathrm{ext}} = 110$ mT.

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