Spin-photon quantum interface in quantum dots

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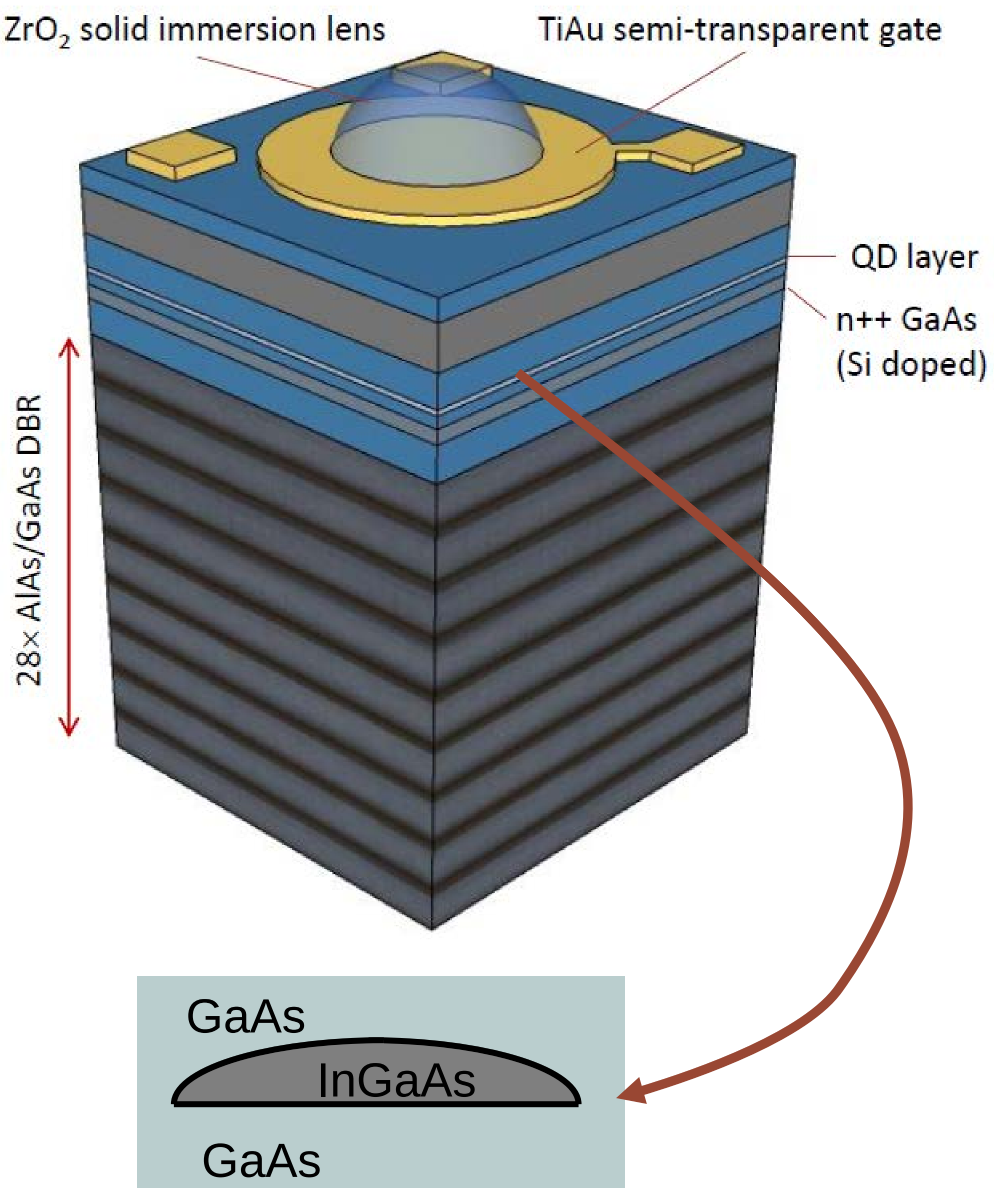
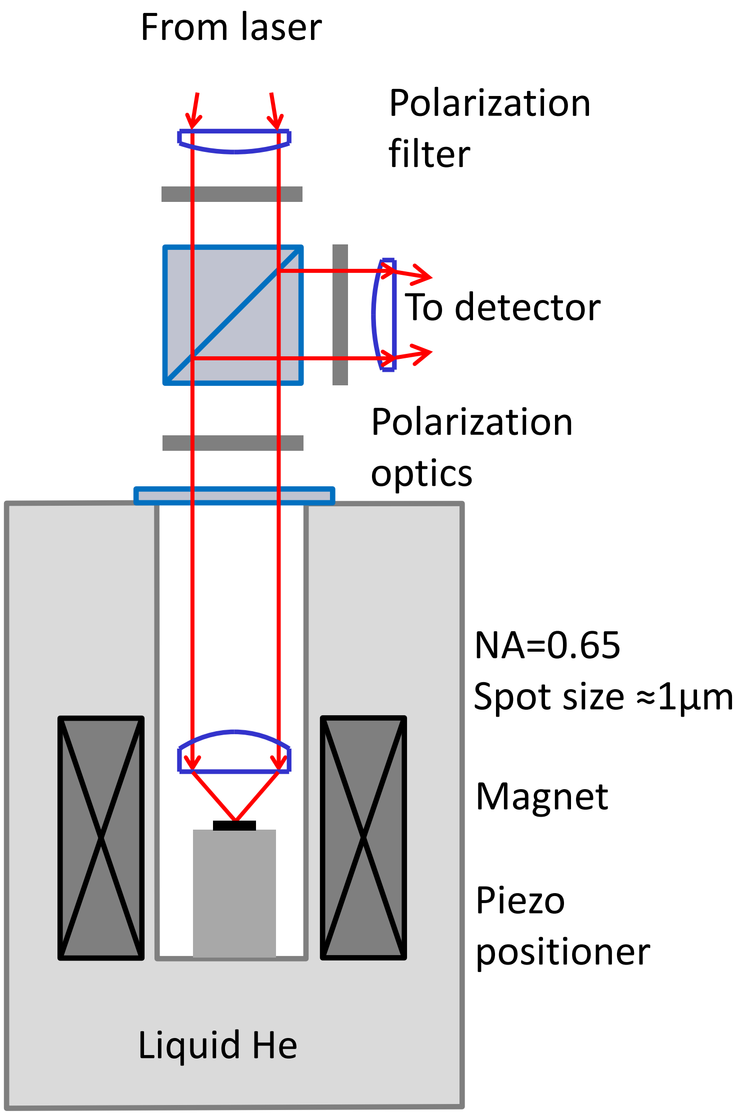
Spin-photon quantum interface

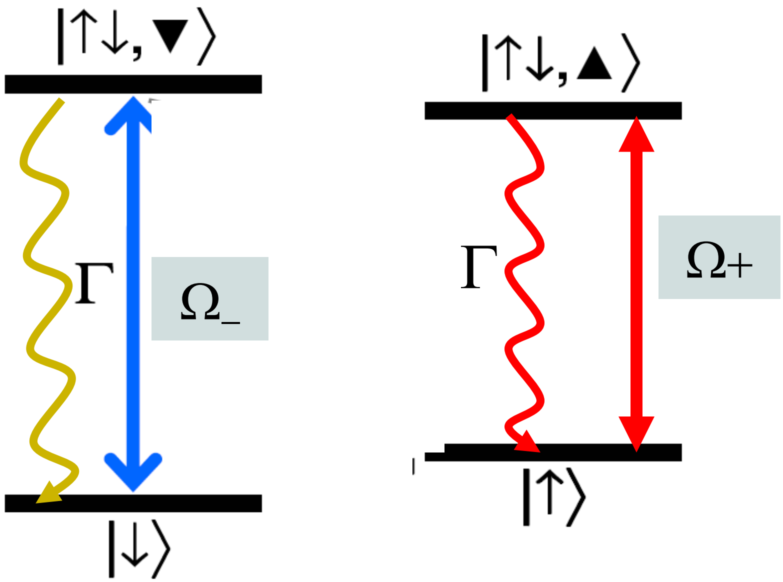
- GaAs based semiconductors exhibit highly efficient spin-dependent optical transitions.
- Photonic nanostructures allow for efficient extraction of photons (Lukin).

Resonant quantum dot Spectroscopy





Strong spin-polarization correlations: Faraday geometry ($B_{ext} = B_z$)



Γ: spontaneous emission rate

Ω: laser coupling (Rabi) frequency

- QD with a spin-up (down) electron only absorbs and emits σ+ (σ-) photons – a recycling transition similar to that used in trapped ions.

  ⇨ Spin measurement

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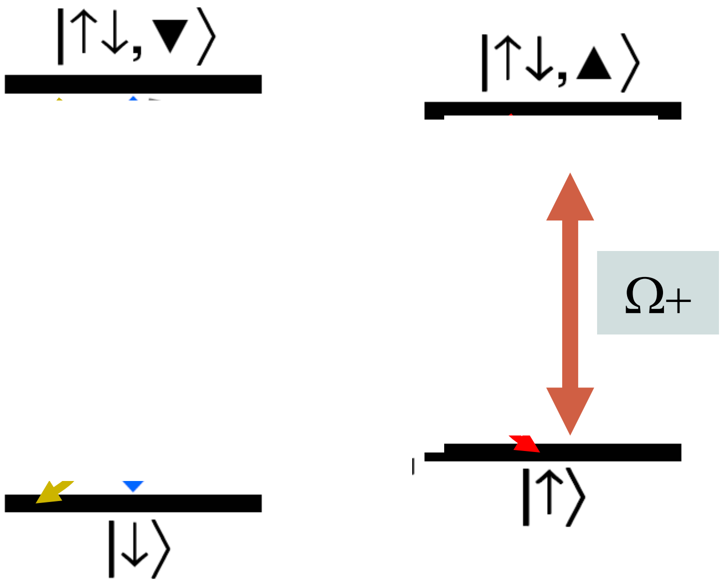

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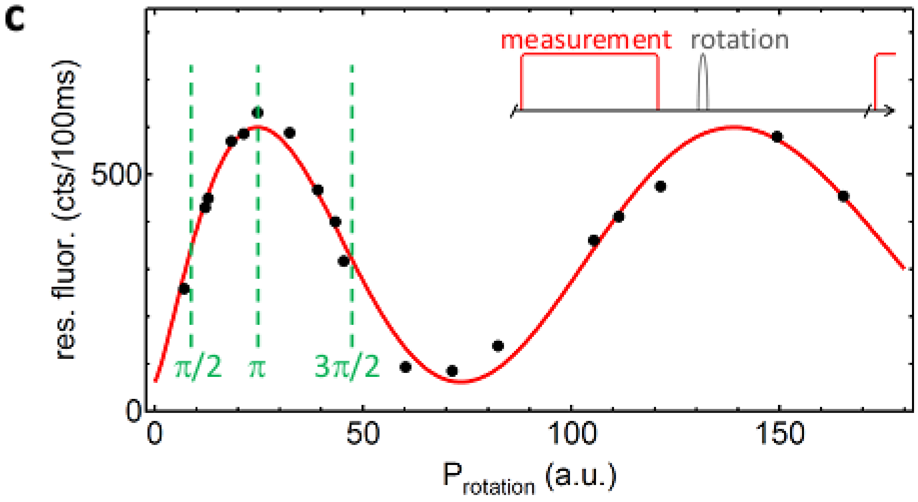
  ⇨ Spin measurement

- An off-resonant σ+ laser causes ac-Stark shift only for the |↑> state, acting as an effective magnetic field along the z-direction.

Spin rotation using off-resonant circularly polarized lasers

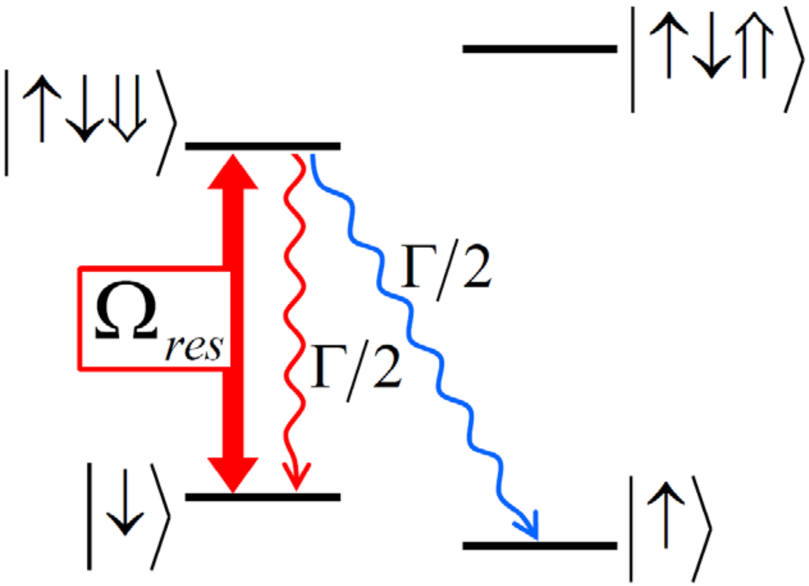
- External field along x ($B_{ext} = B_x$): quantization axis orthogonal to the laser-induced effective field



Awschalom, Yamamoto

Different selection rules in Voigt geometry ($B_{ext} = B_x$)

Excitation of a trion state results in either emission of a H polarized red photon to |↓> state or a V polarized blue photon to |↑> state, with equal probability.



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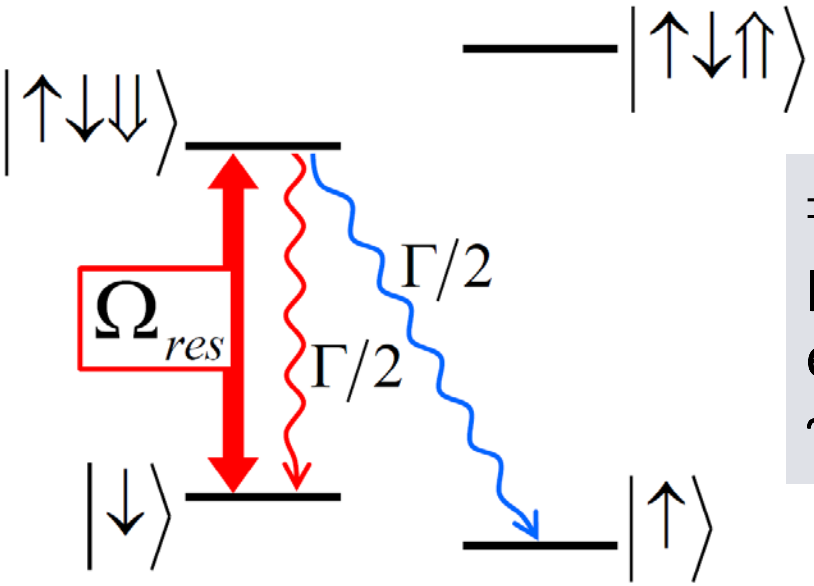
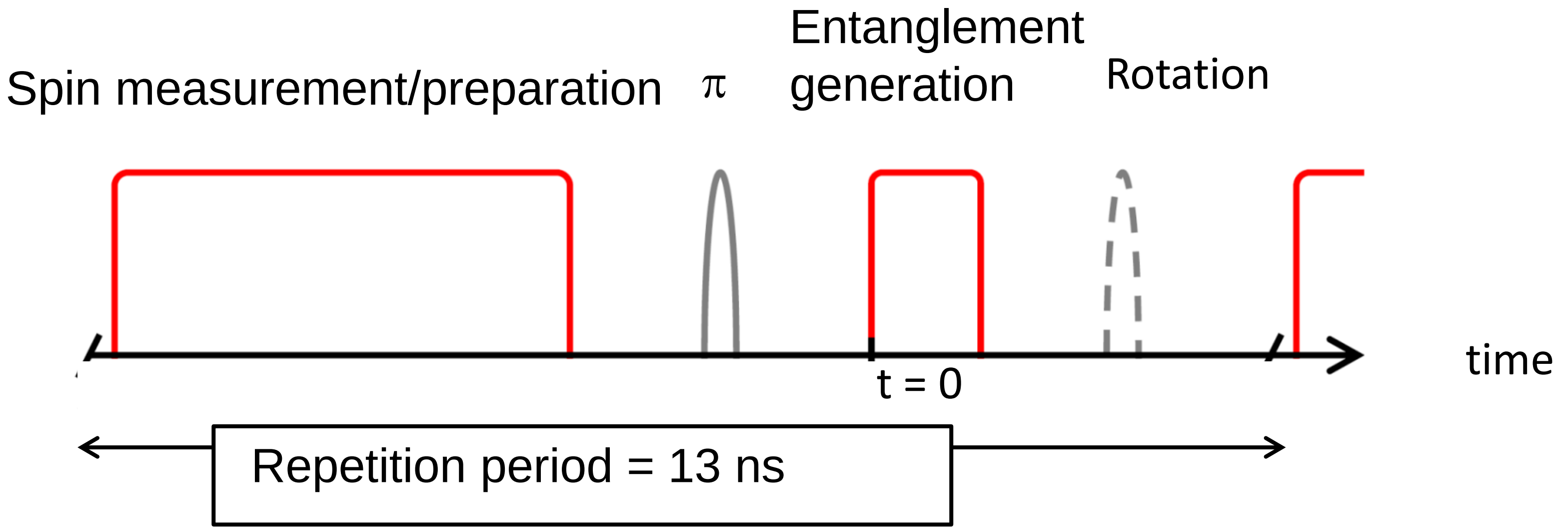


⇒ Spin-photon entanglement: potentially near-determinsitic entanglement generation at ~1 GHz rate

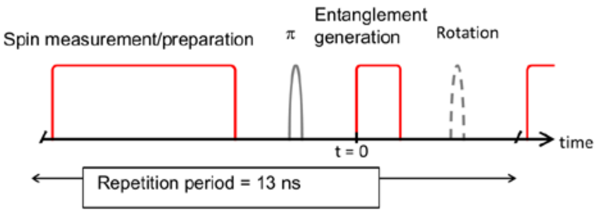
$$|\Psi\rangle = \frac{1}{\sqrt{2}}(|\downarrow\rangle|\omega_{red};H\rangle + i|\uparrow\rangle|\omega_{blue};V\rangle)$$

Similar results by Yamamoto group; earlier work by Monroe,Lukin

Procedure for spin-photon entanglement generation

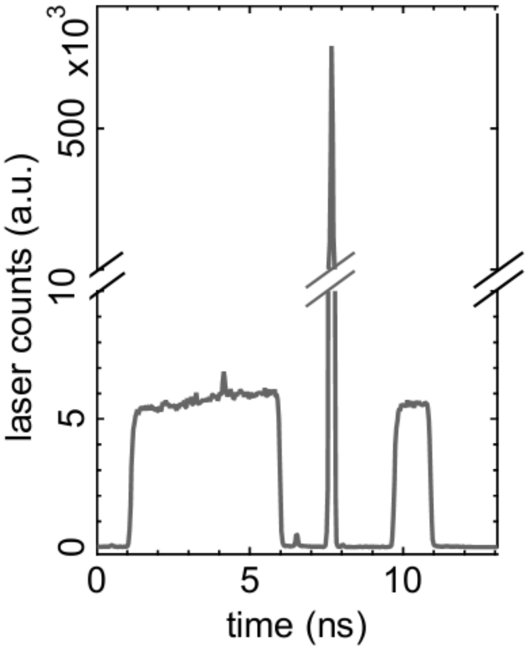


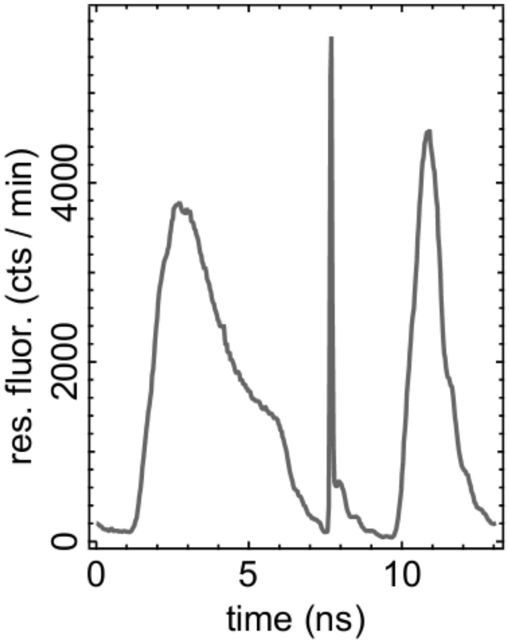
Time resolved resonance fluorescence (RF)

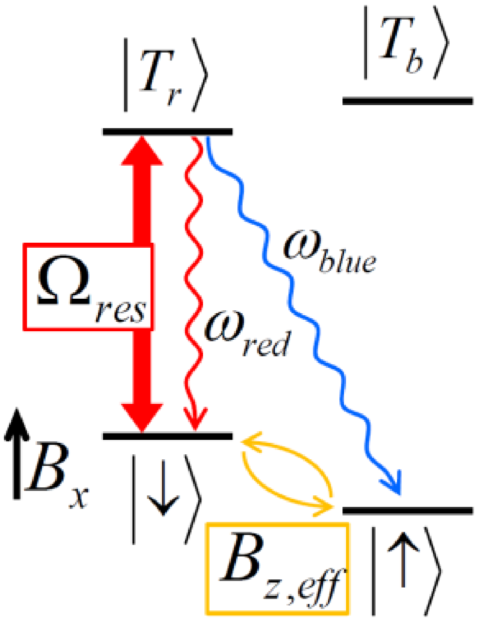


Partially suppressed laser reflection counts

Time-resolved RF measurements





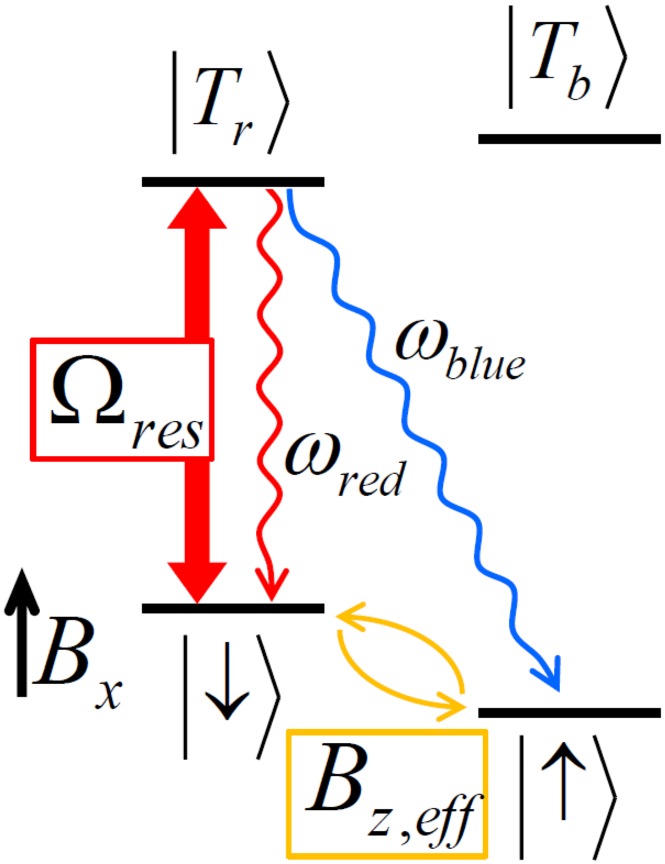


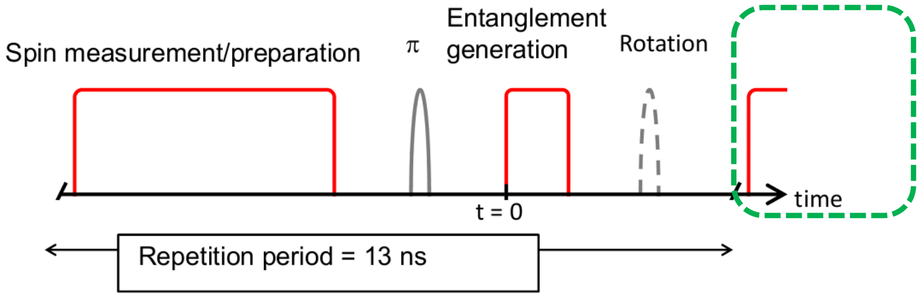
5 ns
spin puming

4 ps
Rotation pulse

1.2 ns
entanglement pulse

Spin measurement and pumping



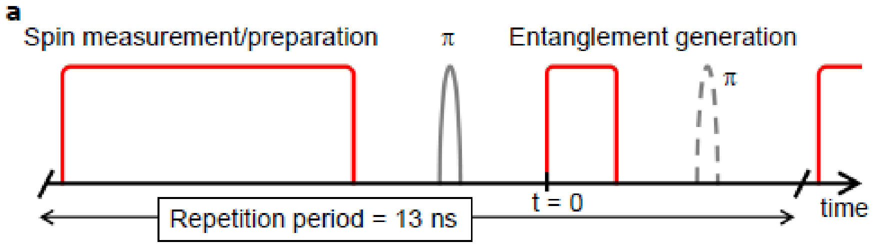


$|\downarrow\rangle$ ➔ ~2 photons/pulse.

$|\uparrow\rangle$ ➔ Nothing.

- The detection of a photon shows the spin is in the state $|\downarrow\rangle$
- At the end of the pulse, the spin is prepared in $|\uparrow\rangle$

Measurement of classical correlations



An additional π-pulse (dashed curve) is applied to realize a heralded measurement in the spin-up state.

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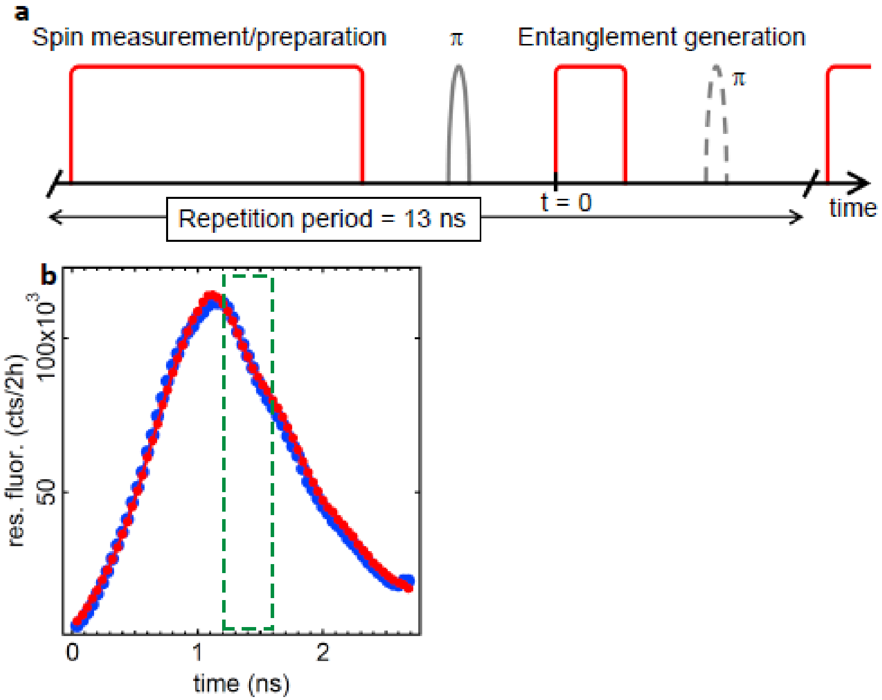

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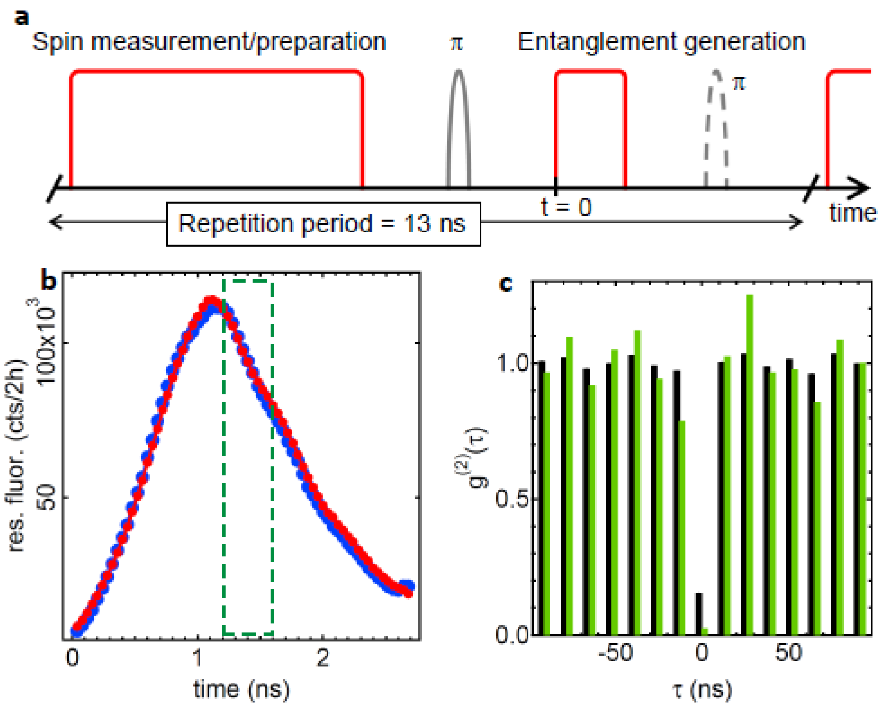

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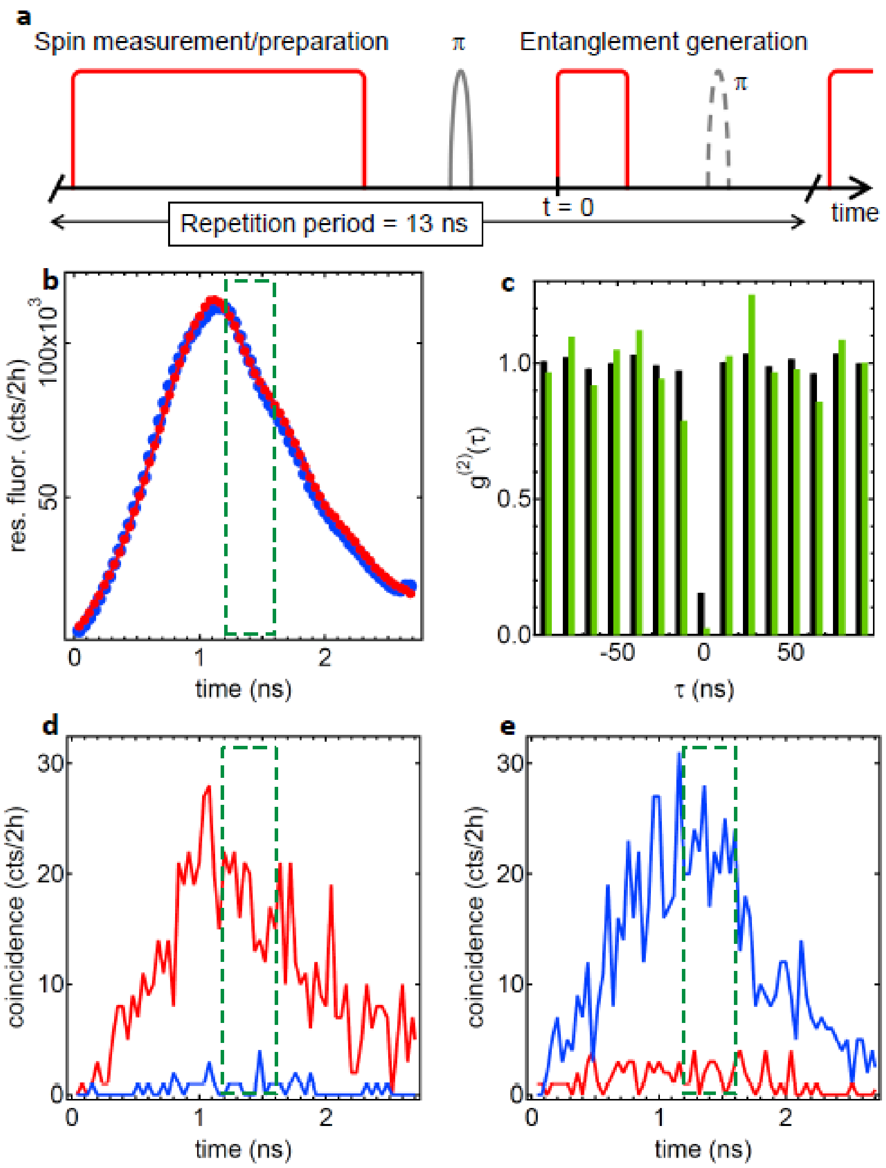

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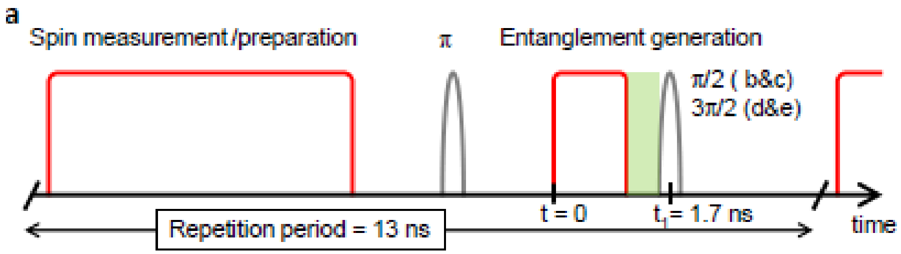
A spin down (up) measurement event ensures that the detected photon is red (blue).

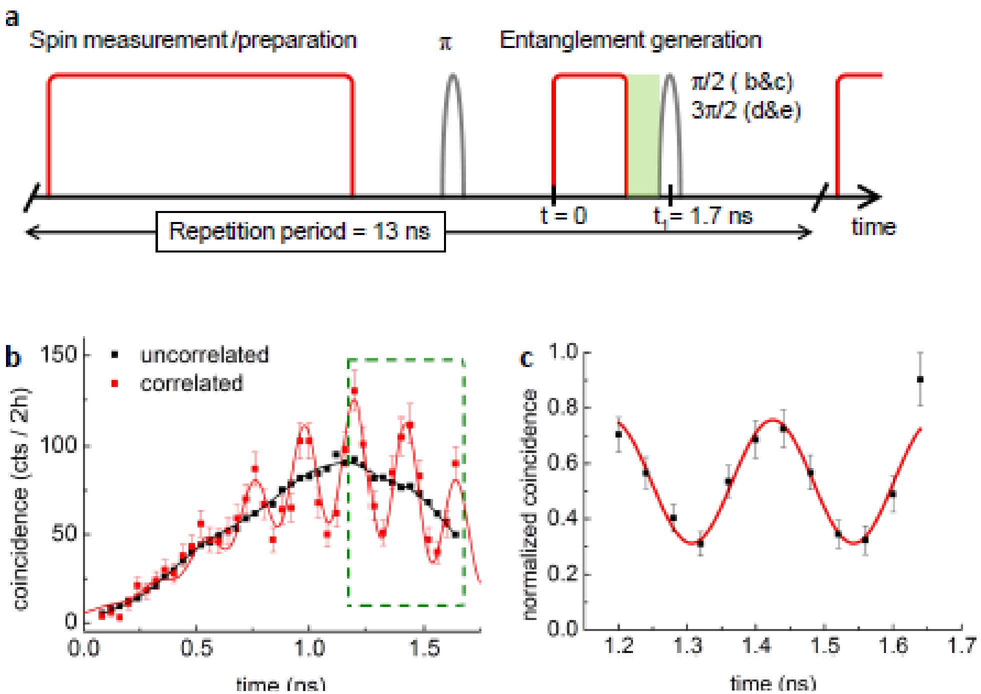
F1=0.87 ± 0.05 in the computational basis measure.ment

Measurement of quantum correlations



- An additional $\pi/2$ or $3\pi/2$-pulse (dashed curve) is applied to measure the spin in $|\uparrow> \pm |\downarrow>$.

Measurement of quantum correlations

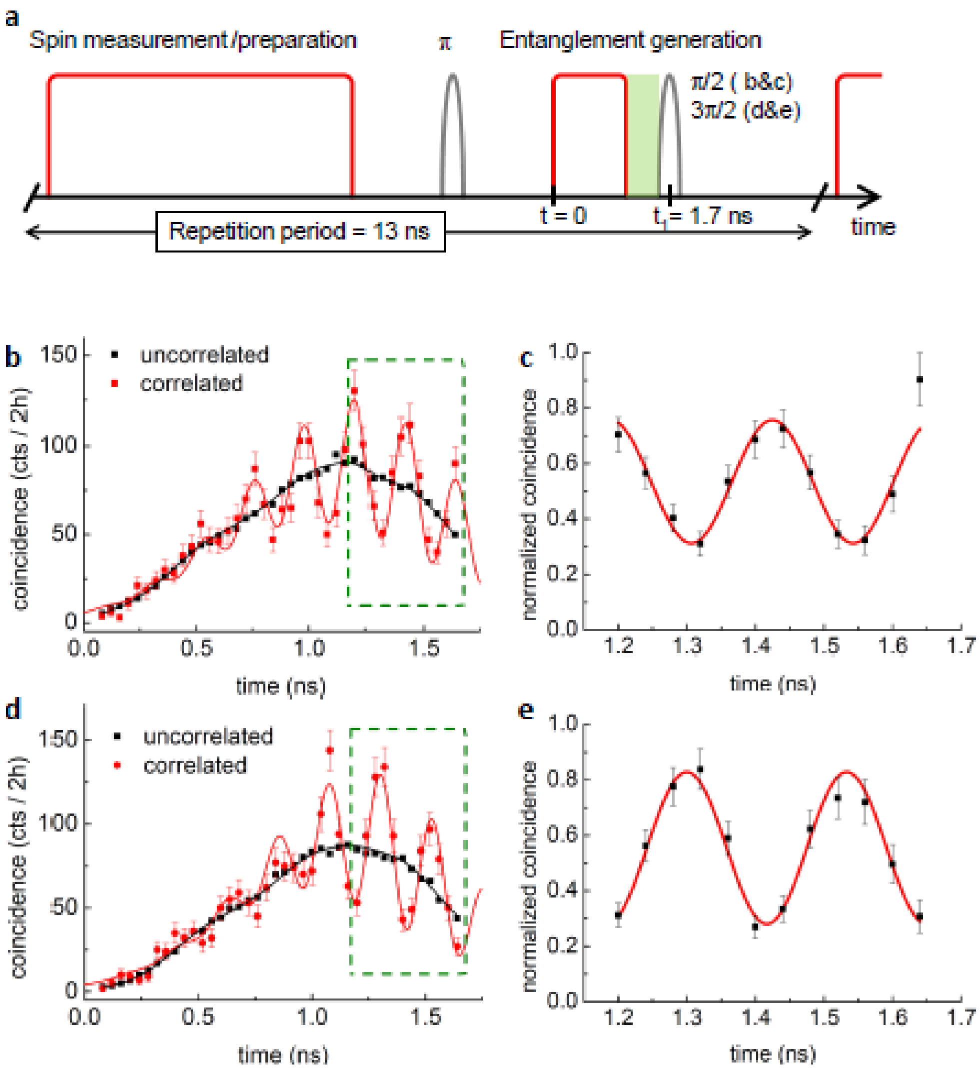


- An additional π/2 or 3π/2-pulse (dashed curve) is applied to measure the spin in |↑> ± |↓>.
- The data in b & c shows the coincidence measurement when π/2-pulse is applied.

$$|\tilde{\Phi}\rangle = \frac{1}{\sqrt{2}}\left(|\omega_{red}\rangle e^{-i\omega_z(t_1-t_g)} - i|\omega_{blue}\rangle\right)$$

⇒ Photon generation events at different times correspond to a measurement of the photonic wave-function in different basis.

Measurement of quantum correlations



- An additional π/2 or 3π/2-pulse (dashed curve) is applied to measure the spin in |↑> ± |↓>.
- The data in b & c shows the coincidence measurement when π/2-pulse is applied.
- The data in d & e shows the coincidence measurement when 3 π/2-pulse is applied.
- F2=0.46 ± 0.04 in the rotated basis measurement; overall fidelity F = 0.67 ± 0.05

Outlook

- Teleportation from a single photon to a solid-state spin
- Spin-Spin entanglement

Thanks to

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