Long-distance coherent coupling in a quantum dot array

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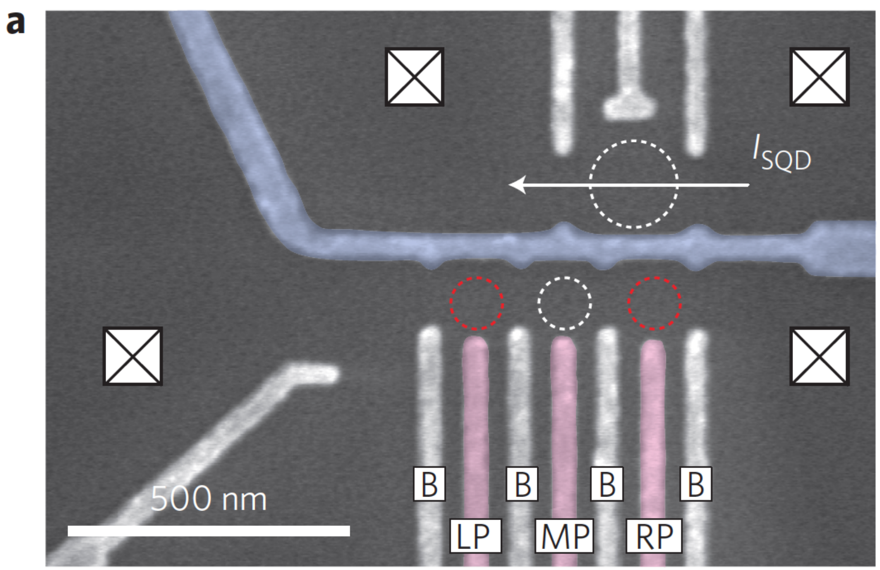
Content

- So far inducing long-distance correlations requires sequential local operations (nearest-neighbour couplings only).

- Here they show, that two distant sites can be tunnel-coupled directly.

- The coupling is mediated by virtual occupation of an intermediate site, with a strength that is controlled via the energy detuning of this site.

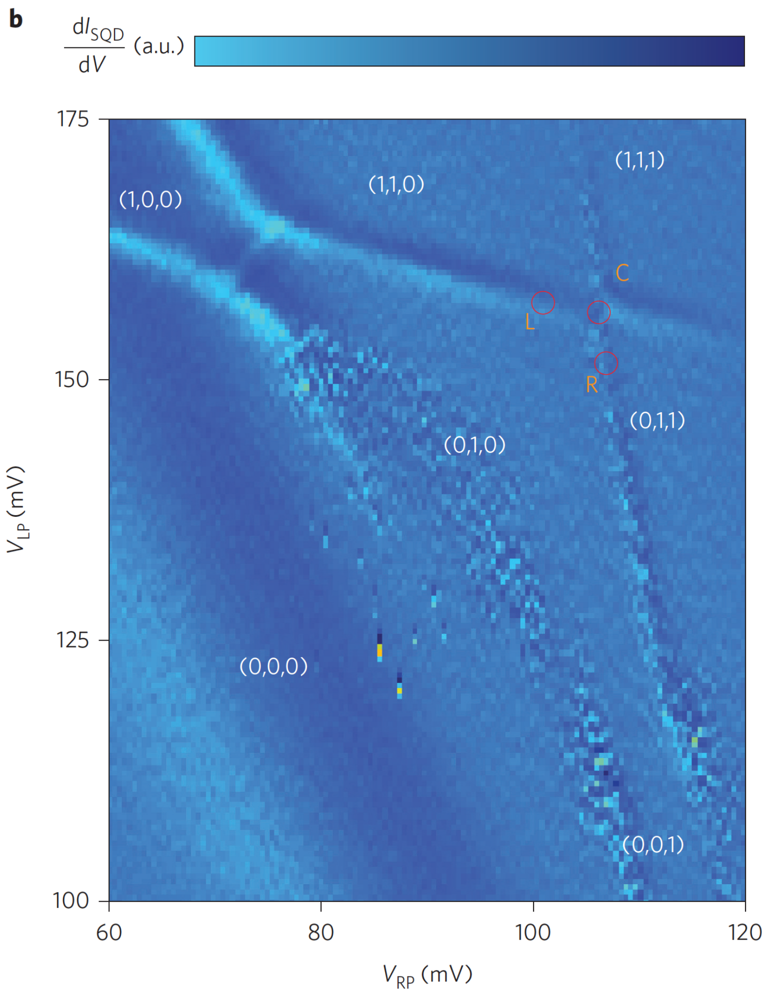
The setup



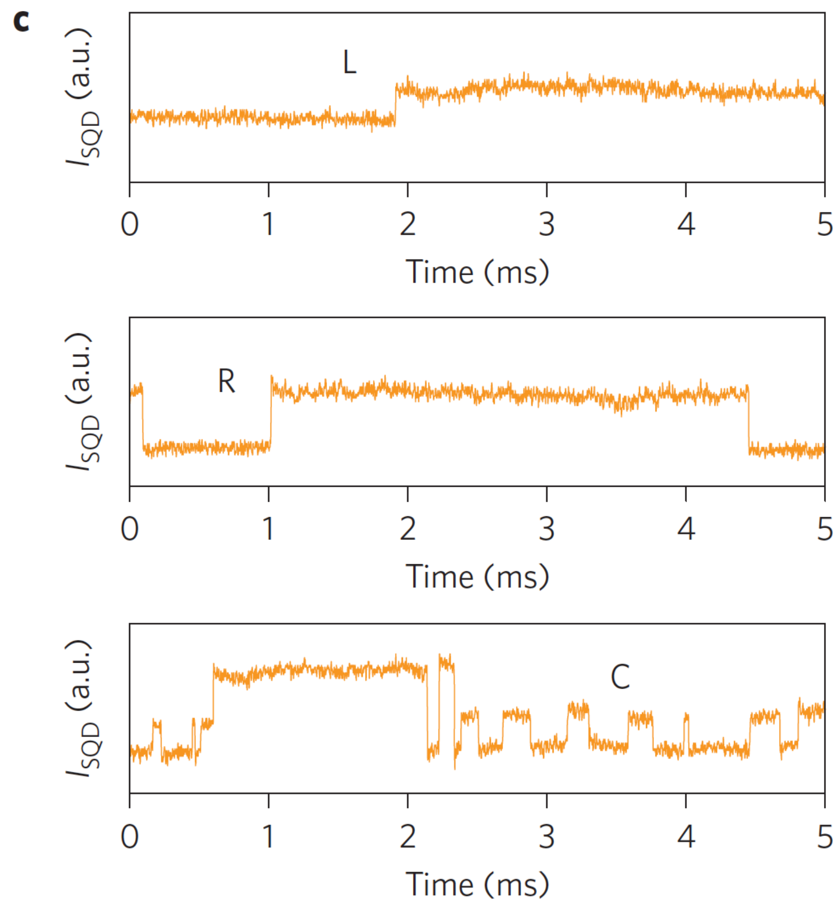
- GaAs/AlGaAs heterostructure $\Rightarrow$ 2DEG.

- Only adjacent dots are connected through tunnel barriers.

- The left and right dots are also tunnel-coupled to the left and right reservoirs, respectively.

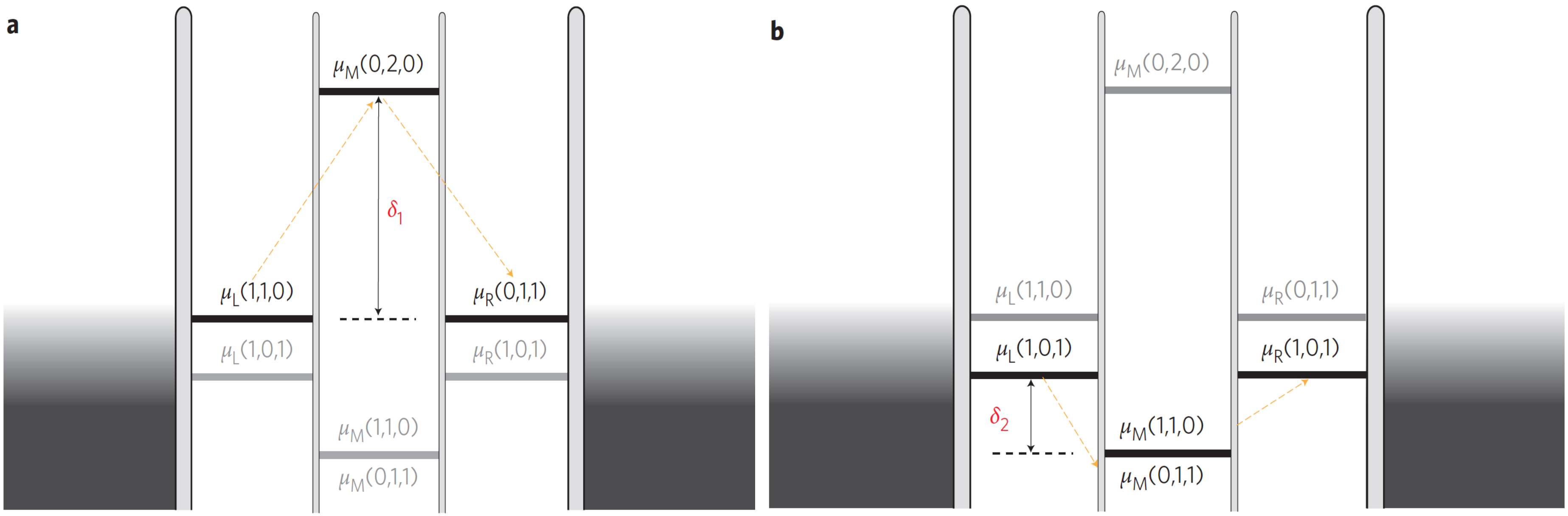


Numerical derivative (along the V_{LP} axis) of current through the SQDas a function of voltage on gates LP and RP.



Real-time traces of the sensing dot reflectometry signal, taken at points L, R, and C.

Co-tunnelling between outer dots



Two possible pathways for co-tunneling between $|110\rangle$ and $|011\rangle$.

Total Tunnel Rate

The Hamiltonian describing the experiments can be expressed in the basis $|\psi_1^{(0)}\rangle = |110\rangle, |\psi_2^{(0)}\rangle = |011\rangle, |\psi_3^{(0)}\rangle = |020\rangle, |\psi_4^{(0)}\rangle = |101\rangle$ as:

$$H = \begin{pmatrix} -\varepsilon/2 & 0 & t_{l1} & t_{l2} \\ 0 & \varepsilon/2 & t_{r1} & t_{r2} \\ t_{l1} & t_{r1} & \delta_1 & 0 \\ t_{l2} & t_{r2} & 0 & \delta_2 \end{pmatrix} \tag{4}$$

We perform a unitary transformation of this Hamiltonian, to express it in the eigenbasis of its first-order perturbation: $H' = U^\dagger H U$, where, as $\varepsilon << \delta_{1,2}$:

$$U = \begin{pmatrix} 1 & 0 & t_{l1}/\delta_1 & t_{l2}/\delta_2 \\ 0 & 1 & t_{r1}/\delta_1 & t_{r2}/\delta_2 \\ -t_{l1}/\delta_1 & -t_{r1}/\delta_1 & 1 & 0 \\ -t_{l2}/\delta_2 & -t_{r2}/\delta_2 & 0 & 1 \end{pmatrix} \tag{5}$$

$$|\psi_1^{(1)}\rangle = |110\rangle - \frac{t_{l1}}{\delta_1}|020\rangle - \frac{t_{l2}}{\delta_2}|101\rangle$$

$$|\psi_2^{(1)}\rangle = |011\rangle - \frac{t_{r1}}{\delta_1}|020\rangle - \frac{t_{r2}}{\delta_2}|101\rangle$$

} basis

$$H = \begin{pmatrix} -\frac{\varepsilon}{2} - \frac{t_{l1}^2}{\delta_1} - \frac{t_{l2}^2}{\delta_2} & \frac{t_{l1}t_{r1}}{\delta_1} + \frac{t_{l2}t_{r2}}{\delta_2} \\ \frac{t_{l1}t_{r1}}{\delta_1} + \frac{t_{l2}t_{r2}}{\delta_2} & \frac{\varepsilon}{2} - \frac{t_{r1}^2}{\delta_1} - \frac{t_{r2}^2}{\delta_2} \end{pmatrix} = \begin{pmatrix} -\varepsilon'/2 & t_{co} \\ t_{co} & \varepsilon'/2 \end{pmatrix}$$

When detuning is zero, adding phenomenologically decoherence

$$\frac{d}{dt}\rho_{11} = -\frac{it_{co}}{\hbar}(\rho_{21} - \rho_{12})$$

$$\frac{d}{dt}\rho_{22} = +\frac{it_{co}}{\hbar}(\rho_{21} - \rho_{12})$$

$$\frac{d}{dt}\rho_{12} = -\frac{\rho_{12}}{T_2} - \frac{it_{co}}{\hbar}(\rho_{22} - \rho_{11})$$

$$\frac{d}{dt}\rho_{21} = -\frac{\rho_{21}}{T_2} + \frac{it_{co}}{\hbar}(\rho_{22} - \rho_{11})$$

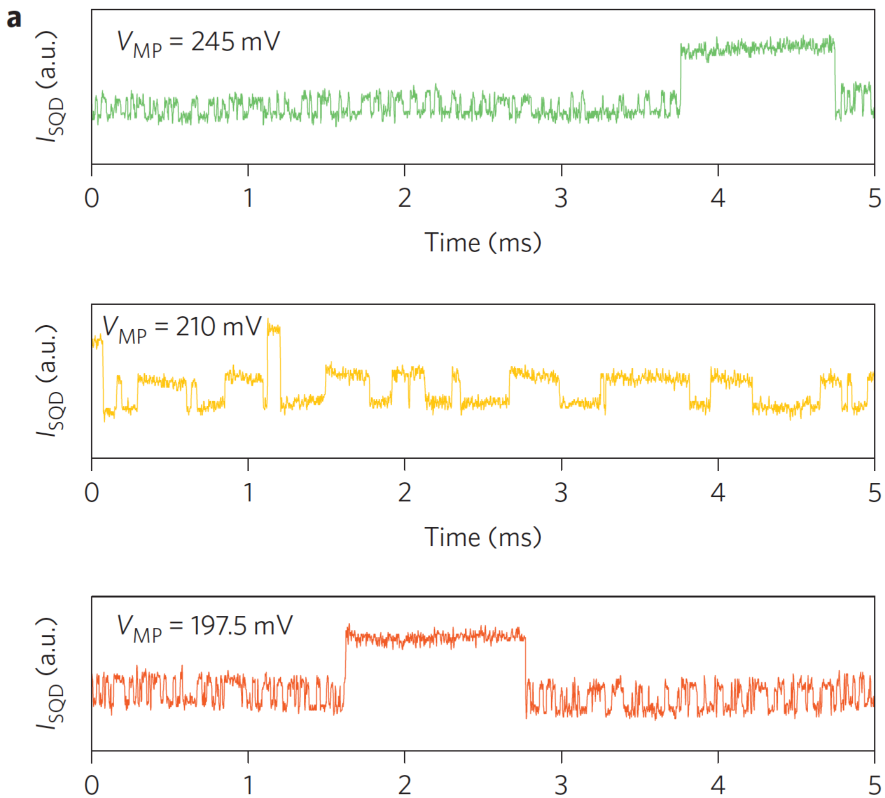
→

$$\Gamma = \frac{2T_2}{\hbar}\left(\frac{t_{l1}^2 t_{r1}^2}{\delta_1^2} + \frac{t_{l2}^2 t_{r2}^2}{\delta_2^2}\right)$$

$(t_{co} << 1/T_2)$,

measurement time is much longer,
than the decoherence time

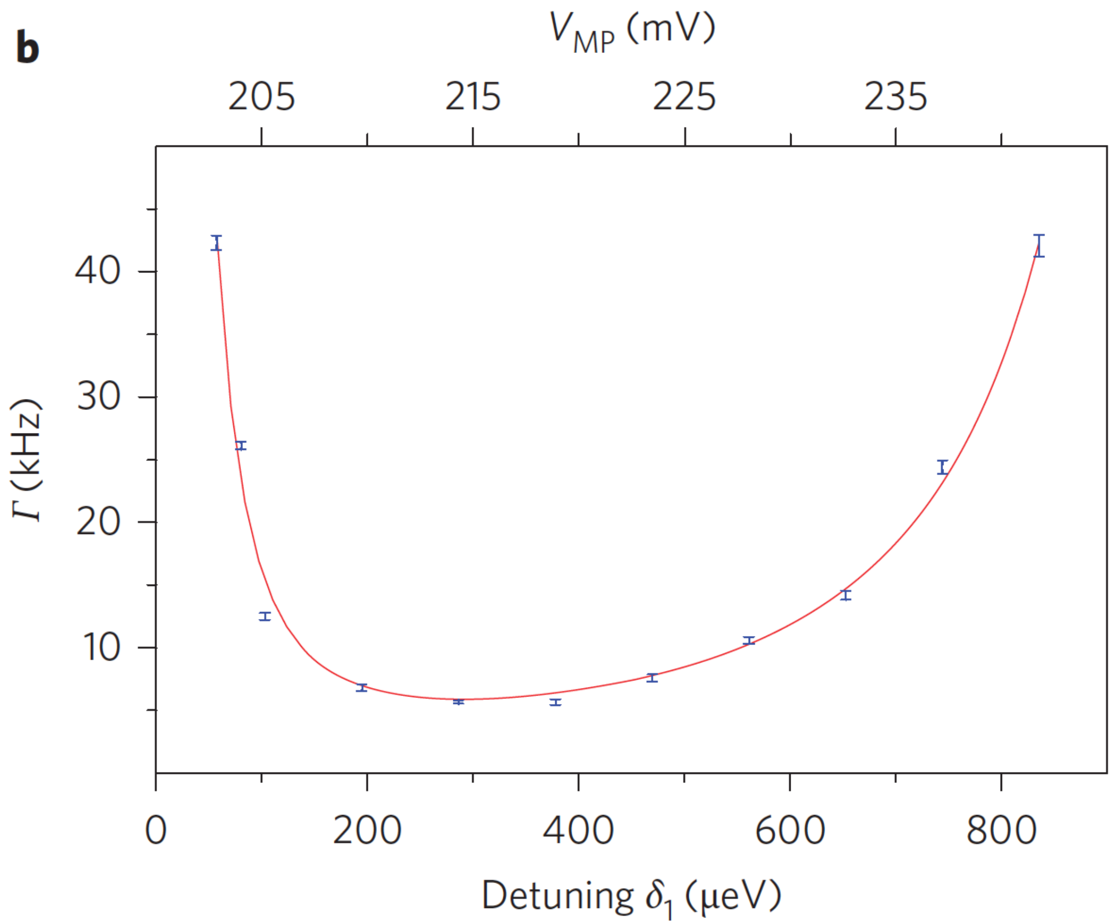
Non-monotonous dependence on detuning



small δ_1, large δ_2

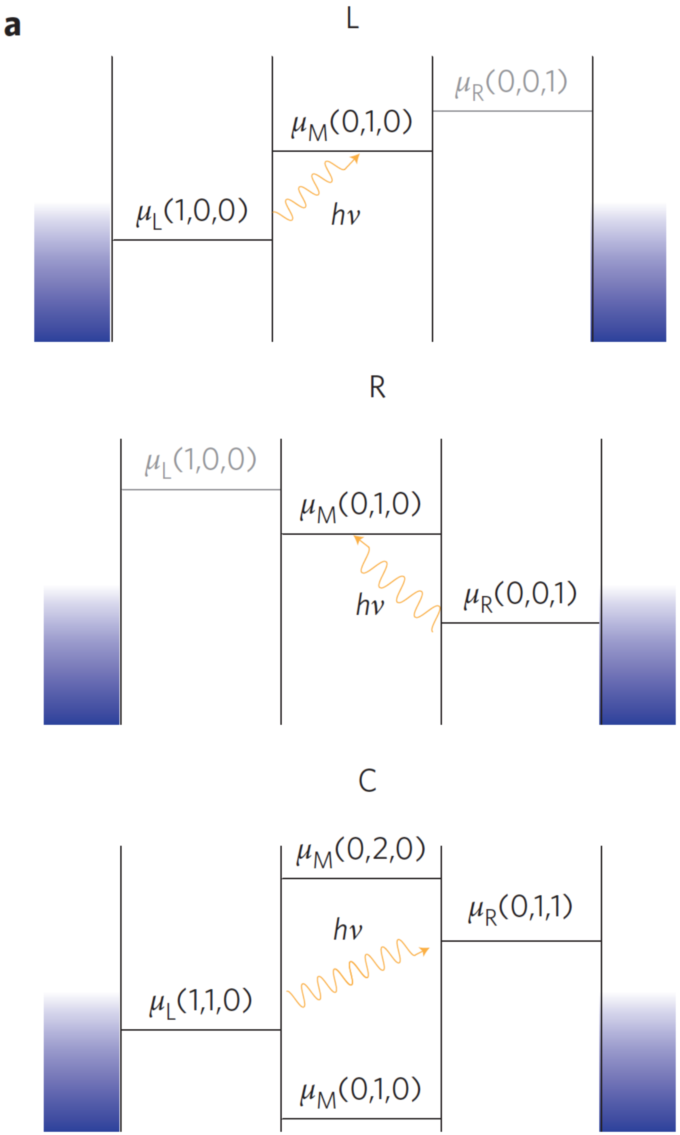
both δ_2 and δ_1 are large

small δ_2, large δ_1

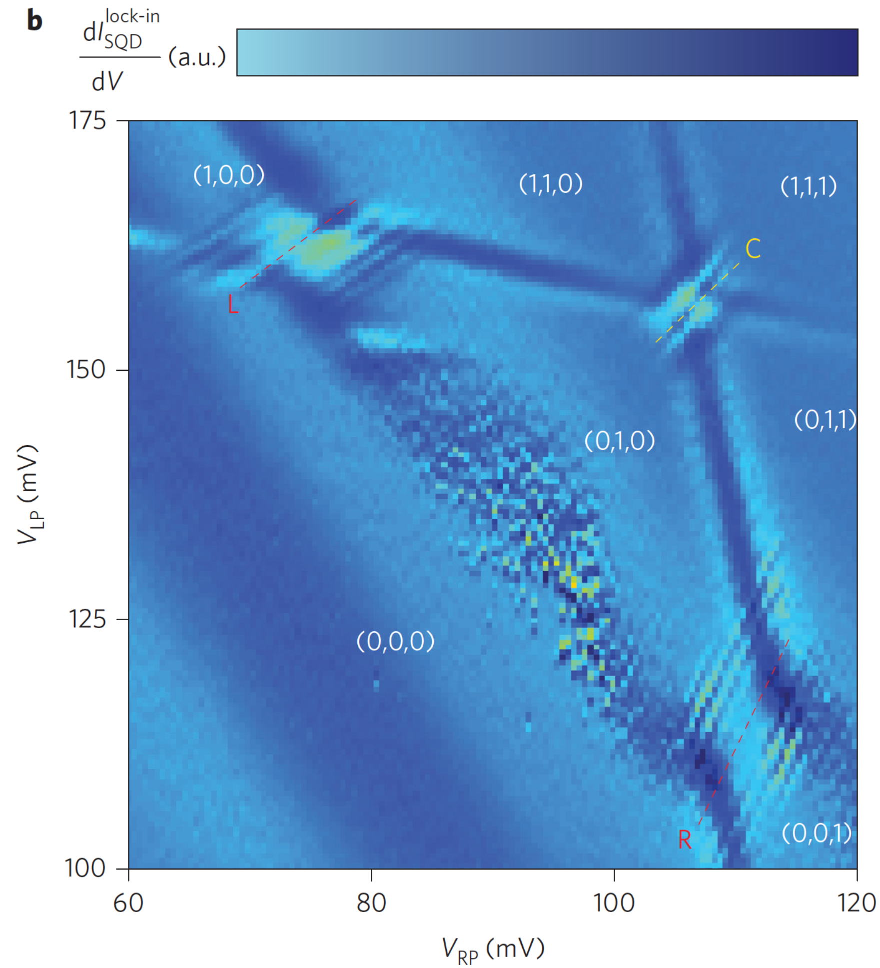


Extracted data about rate is well fitted by previously derived formula, non-monotonous dependence indicate co-tunnelling.

PAT and PACT



a
L
$\mu_R(0,0,1)$
$\mu_M(0,1,0)$
$\mu_L(1,0,0)$
$h\nu$
R
$\mu_L(1,0,0)$
$\mu_M(0,1,0)$
$h\nu$
$\mu_R(0,0,1)$
C
$\mu_M(0,2,0)$
$h\nu$
$\mu_R(0,1,1)$
$\mu_L(1,1,0)$
$\mu_M(0,1,0)$



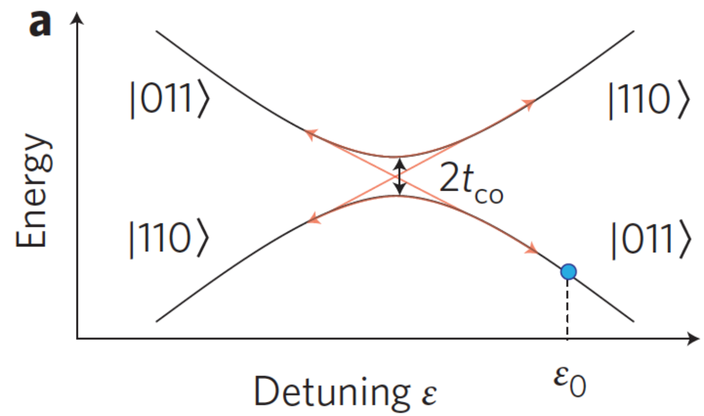
b
$\frac{dI_{SQD}^{lock-in}}{dV}$ (a.u.)
175
150
125
100
V_{LP} (mV)
60
80
100
120
V_{RP} (mV)
(1,0,0)
(1,1,0)
(1,1,1)
(0,1,0)
(0,1,1)
(0,0,0)
(0,0,1)
L
C
R

For previously derived Hamiltonian they put detuning depending on the frequency, as it was a microwave excitation applied to LP gate.

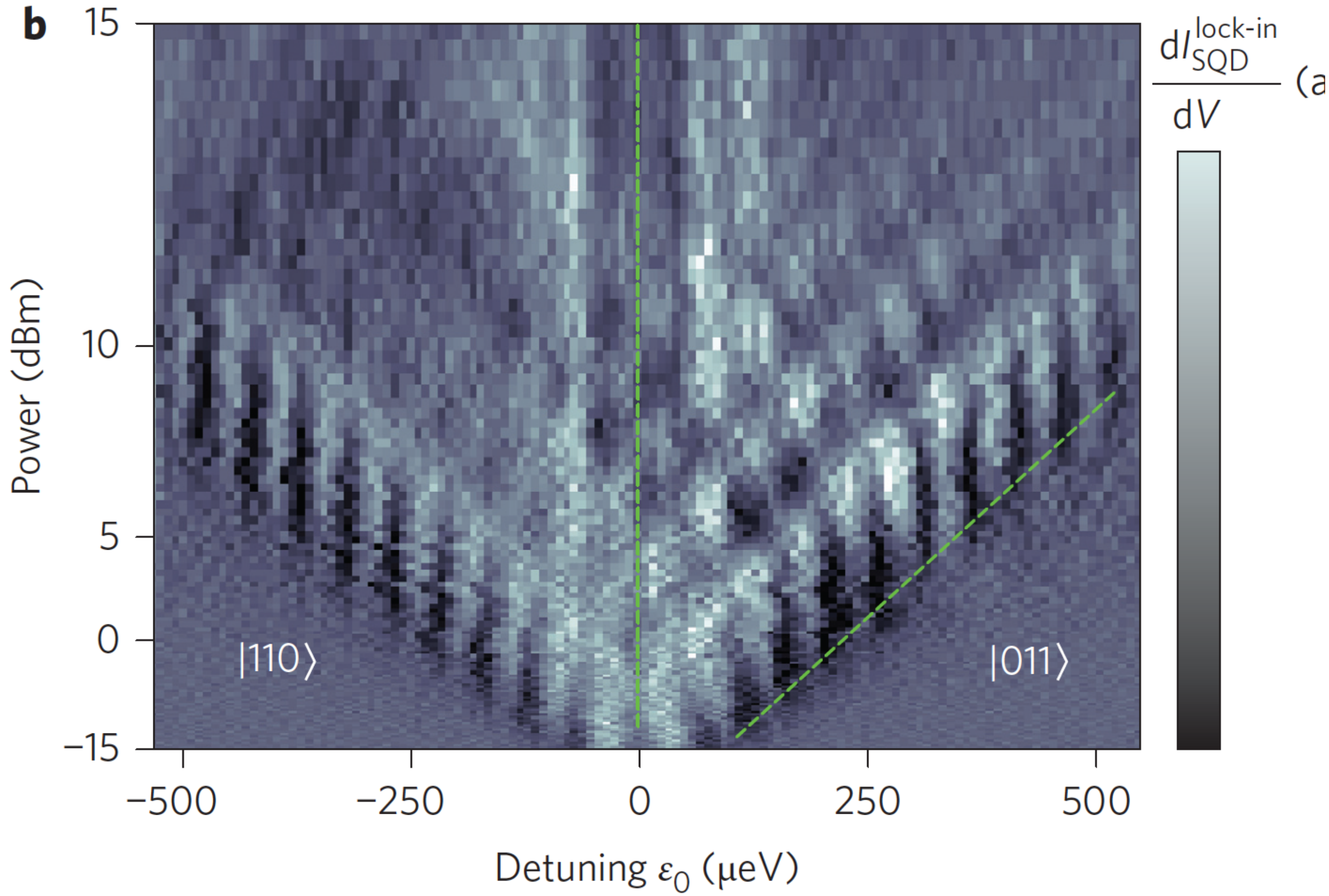
$$\varepsilon \rightarrow \varepsilon_0 + Aexp(i\omega t)$$

$$H = \begin{pmatrix} -\varepsilon_0'/2 - Aexp(i\omega t) & t_{co} \\ t_{co} & \varepsilon_0'/2 + Aexp(i\omega t) \end{pmatrix}$$

It is exactly Landau-Zener-Schtueckelberg Hamiltonian, so all LZS physics can be applied to PACT.



$$\Delta\Theta_{12} = \frac{1}{\hbar}\int_{t_1}^{t_2} \varepsilon(t)\mathrm{d}t$$



Conclusions

- They demonstrated an effective coherent co-tunnel coupling between the outer dots in a triple quantum dot, which is mediated by virtual occupation of levels on the middle dot.

- The coupling strength can be controlled via detuning between the relevant middle and outer dot levels and agrees well with theoretical predictions.