Singlet-Triplet and Doublet-Doublet Kondo Effect in an Artificial Atom

S. Sasaki,[1] * S. Amaha[2], N. Asakawa[2] and S. Tarucha[1,2,3]

[1]NTT Basic Research Laboratories
[2]Department of Physics, University of Tokyo
[3]Mesoscopic Correlation Project, ERATO, JST

* *E-mail: satoshi@nttbrl.jp*

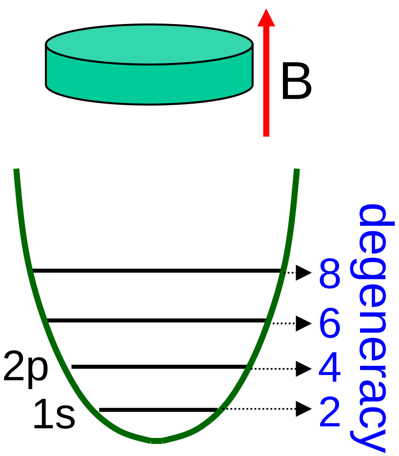
Outline

- Quantum dot is suitable for the study of the Kondo effect
  various parameters tunable (gate voltage, magnetic field etc).
  ··· manipulation of spin state is easy
- Advantage of using a vertical quantum dot = artificial atom
  ··· well defined electron number (down to "0") and spin state
- Experimental results
  Dot – lead coupling $\Gamma \sim 400\mu eV$
  singlet-triplet Kondo for even *N*
  ··· similar to our previous report (Nature **405** (2000) 764)
  doublet-doublet Kondo for odd *N*
  doublet with orbital degeneracy ··· *New!*

Electronic states in a circular artificial atom

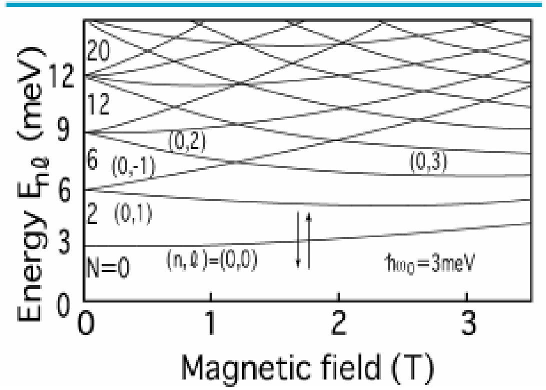
N and *S* clearly defined!

2D disk shaped dot

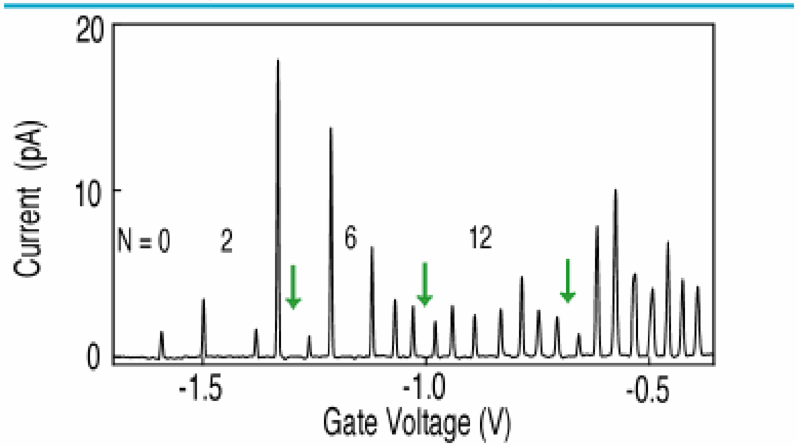


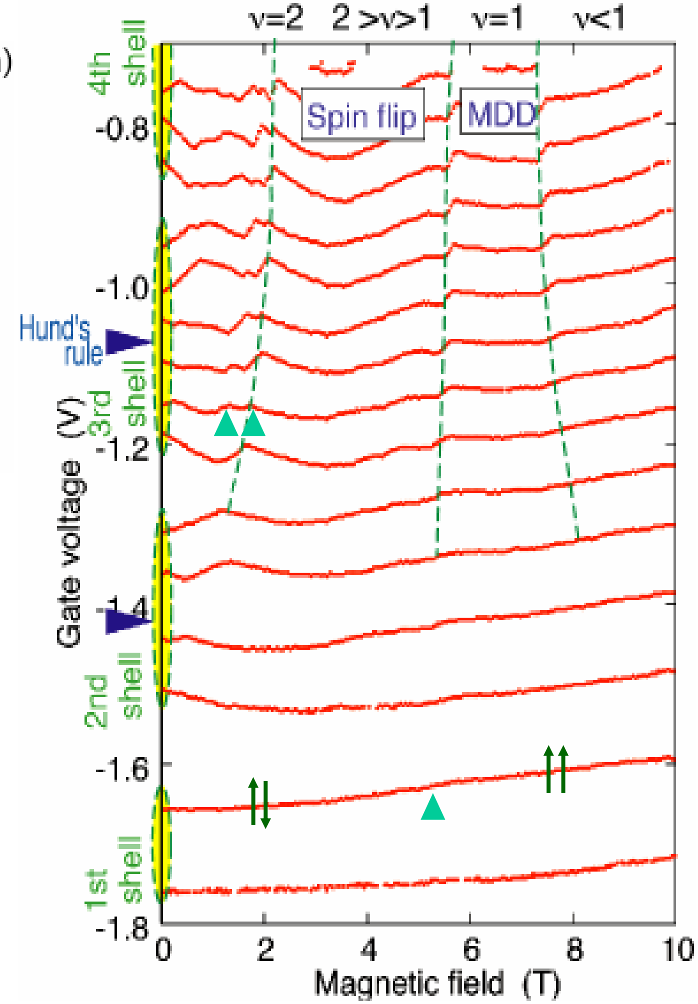
Harmonic potential

Fock-Darwin states (single-particle Hamiltonian)



Addition energy spectrum: shell filling and Hund's rule

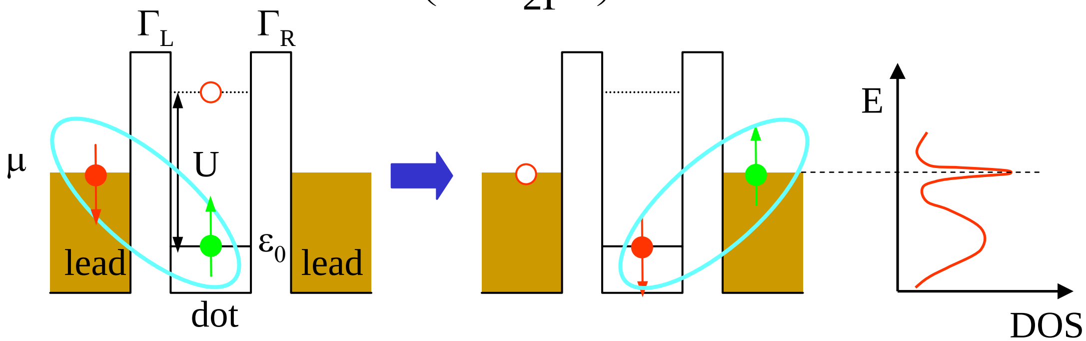




Kondo effect in quantum dots

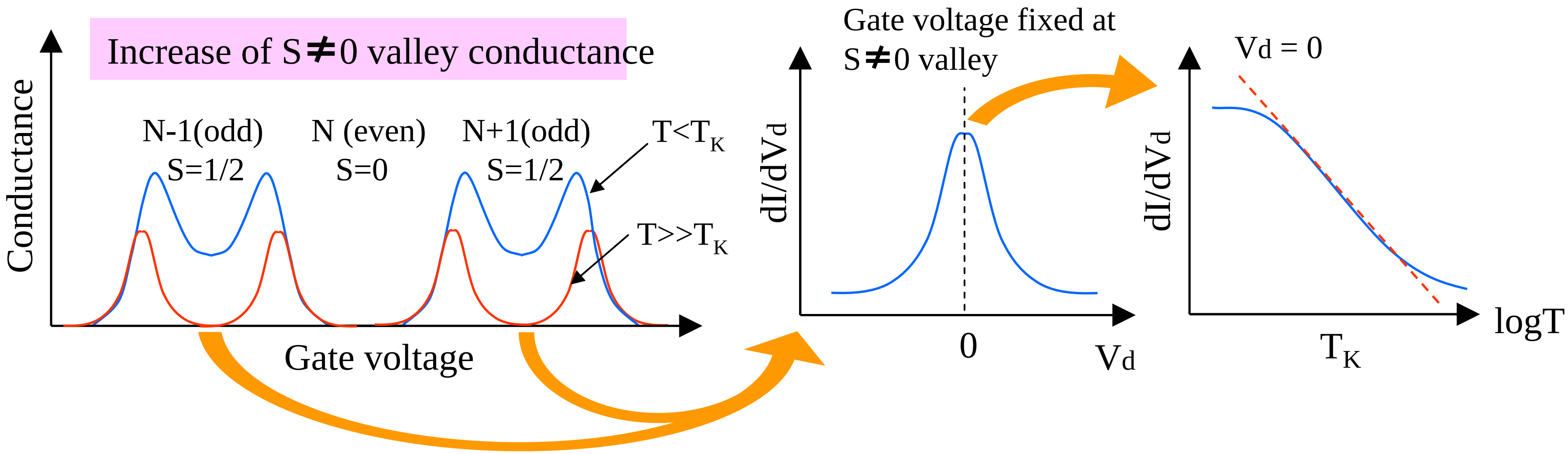
Quantum dot:
manipulation of spin state via various parameters (gate voltage, magnetic field etc.) ⇒ detailed analysis of the Kondo effect

$$T < T_K \approx \sqrt{\Gamma U}\exp\left(-\pi\frac{\mu-\varepsilon_0}{2\Gamma}\right),\ \Gamma = \Gamma_L + \Gamma_R$$

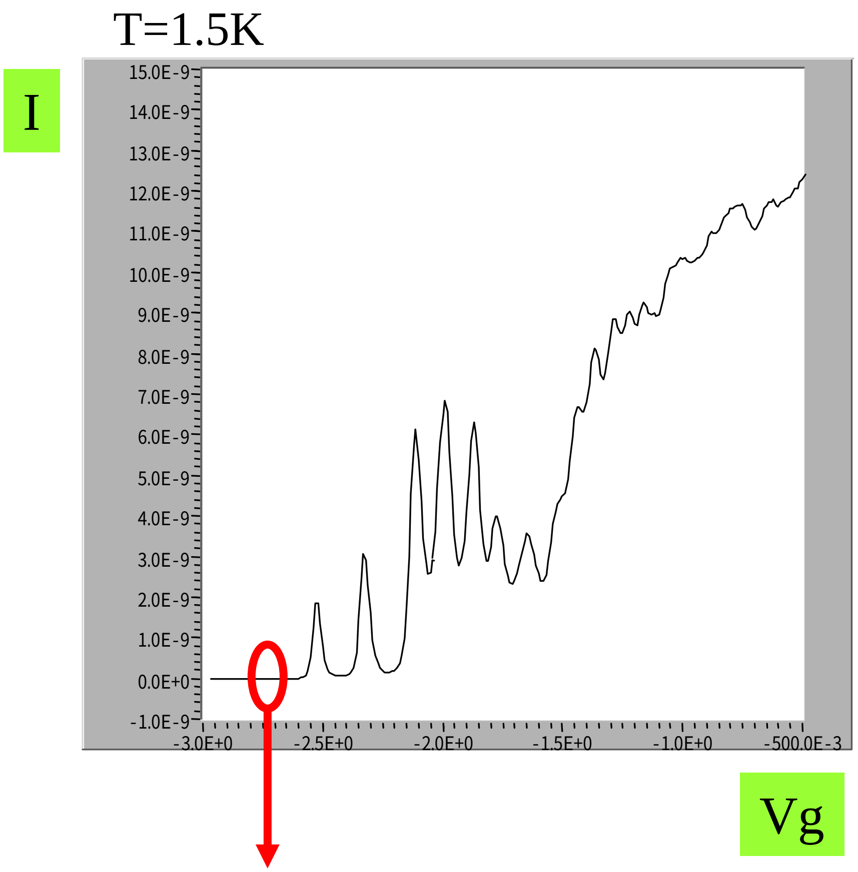


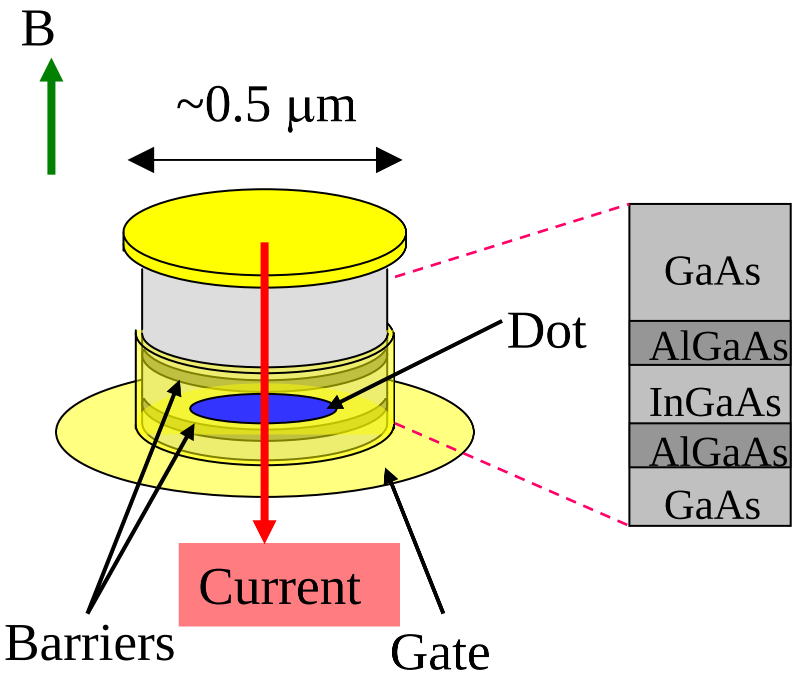
Anti-ferromagnetic spin coupling between dot and leads

Coherent higher-order tunneling



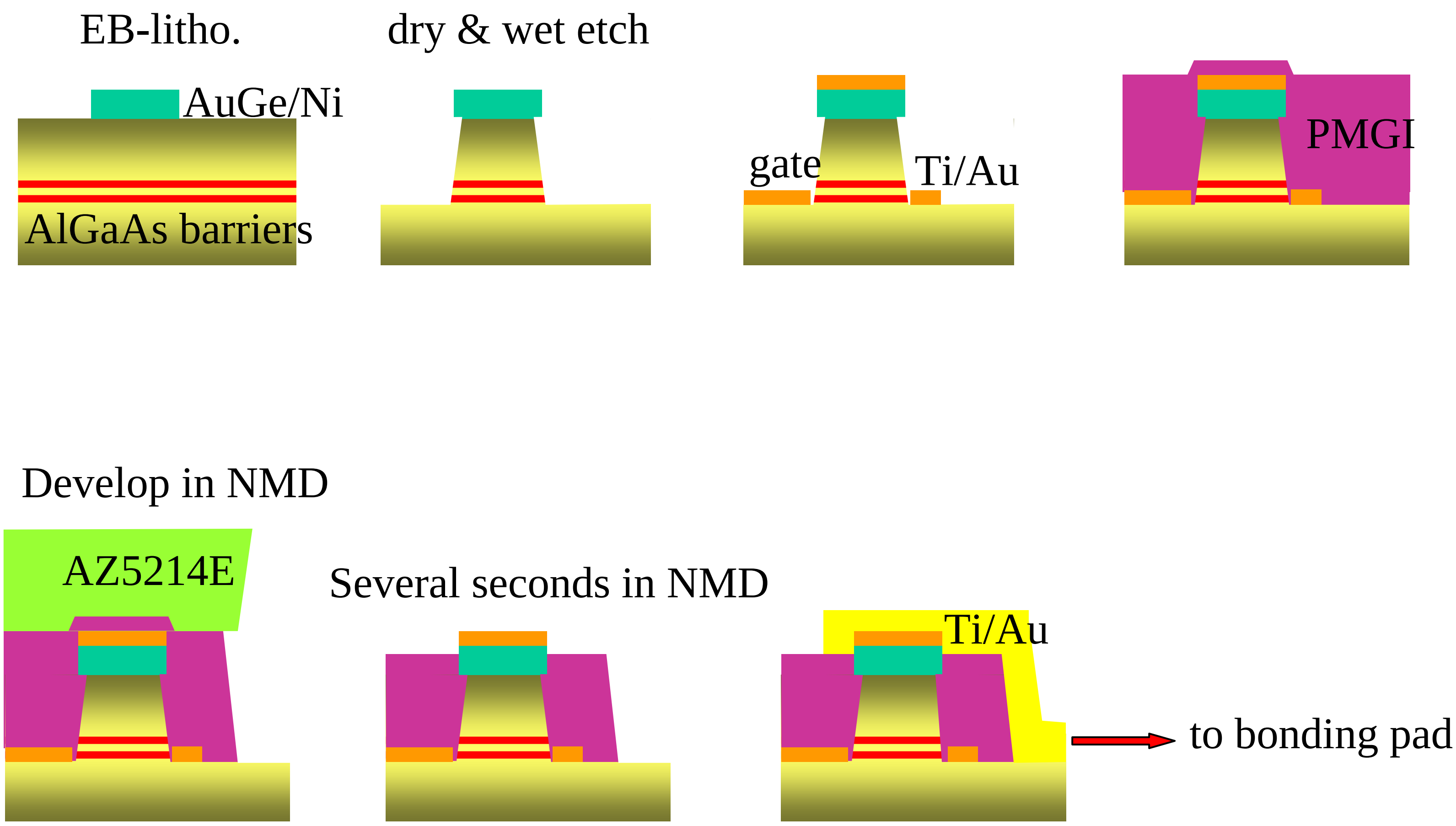
Sample structure (leveling technique)



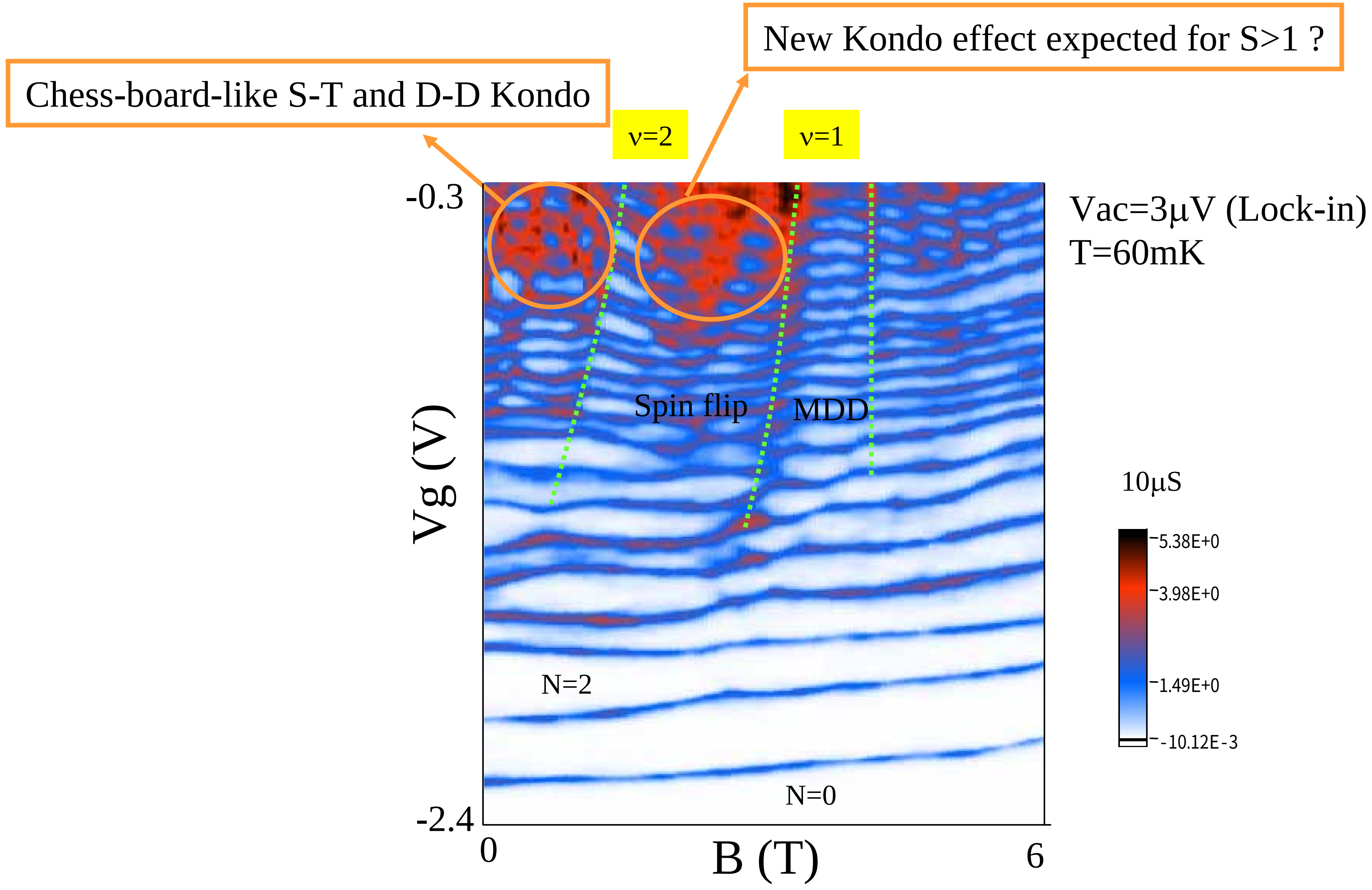


Good pinch-off characteristics

Fabrication process (leveling technique)

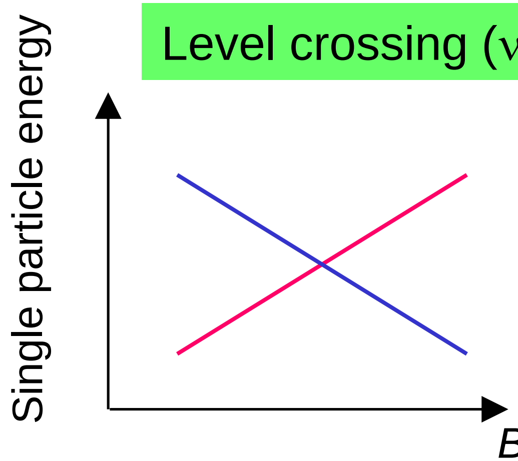


B-N diagram with large Γ (Kondo effect)

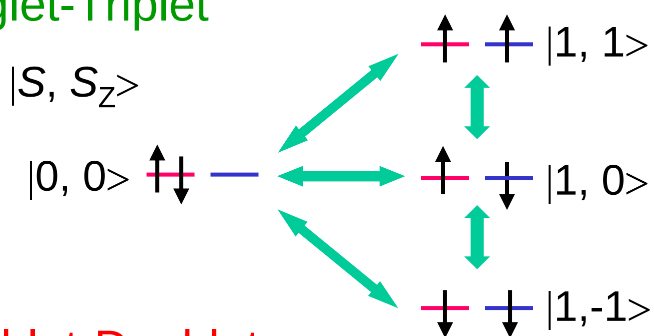


Enhanced Kondo at level crossings

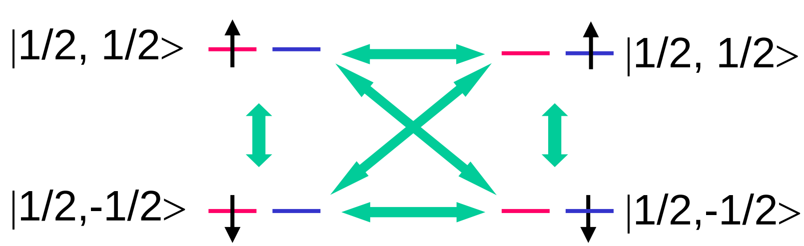
Level crossing (ν=2)



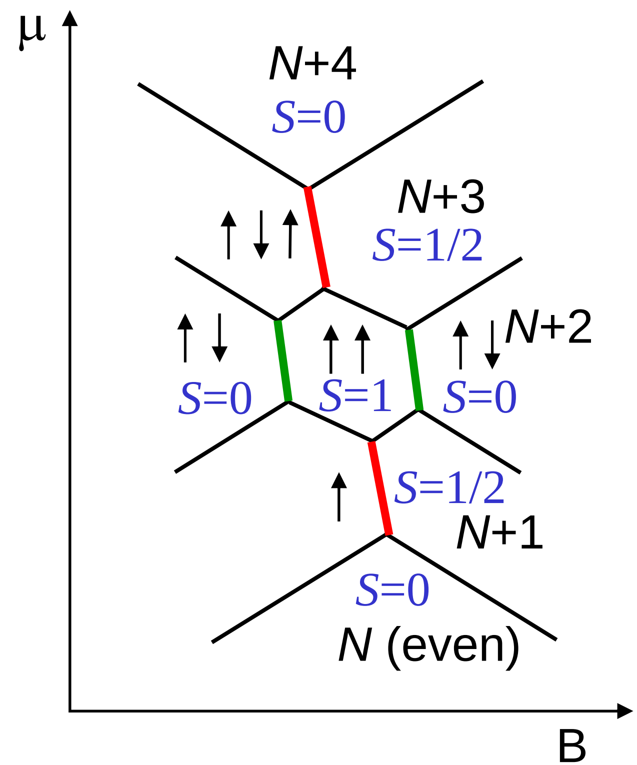
Singlet-Triplet



Doublet-Doublet



$T_K^{S\text{-}T} \sim T_K^{D\text{-}D} > T > T_K^{D}$ ($>> T_K^{T}$)

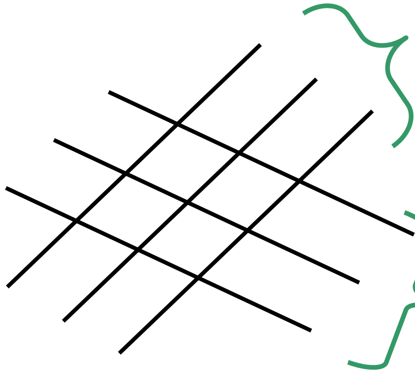


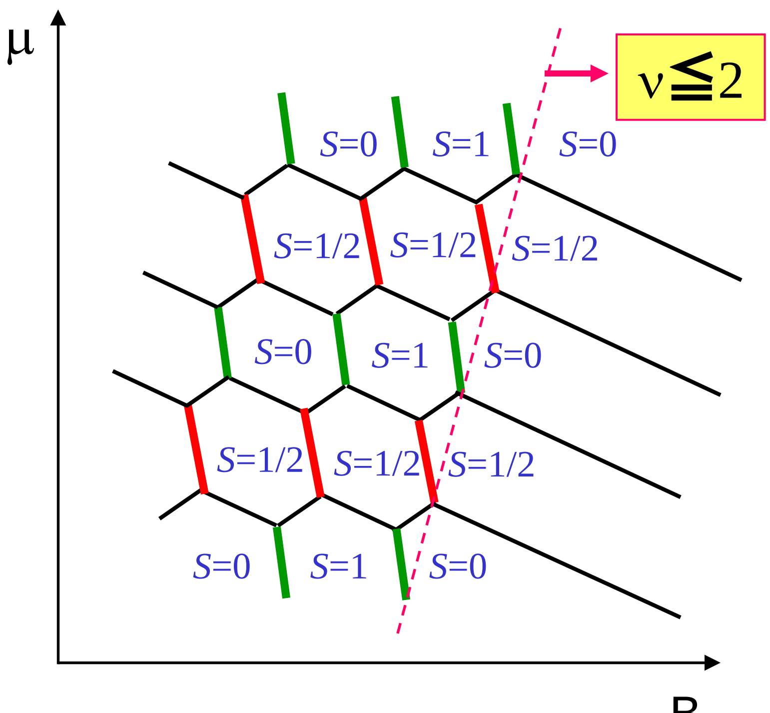
Orbital degeneracy
⇒ Enhanced Kondo

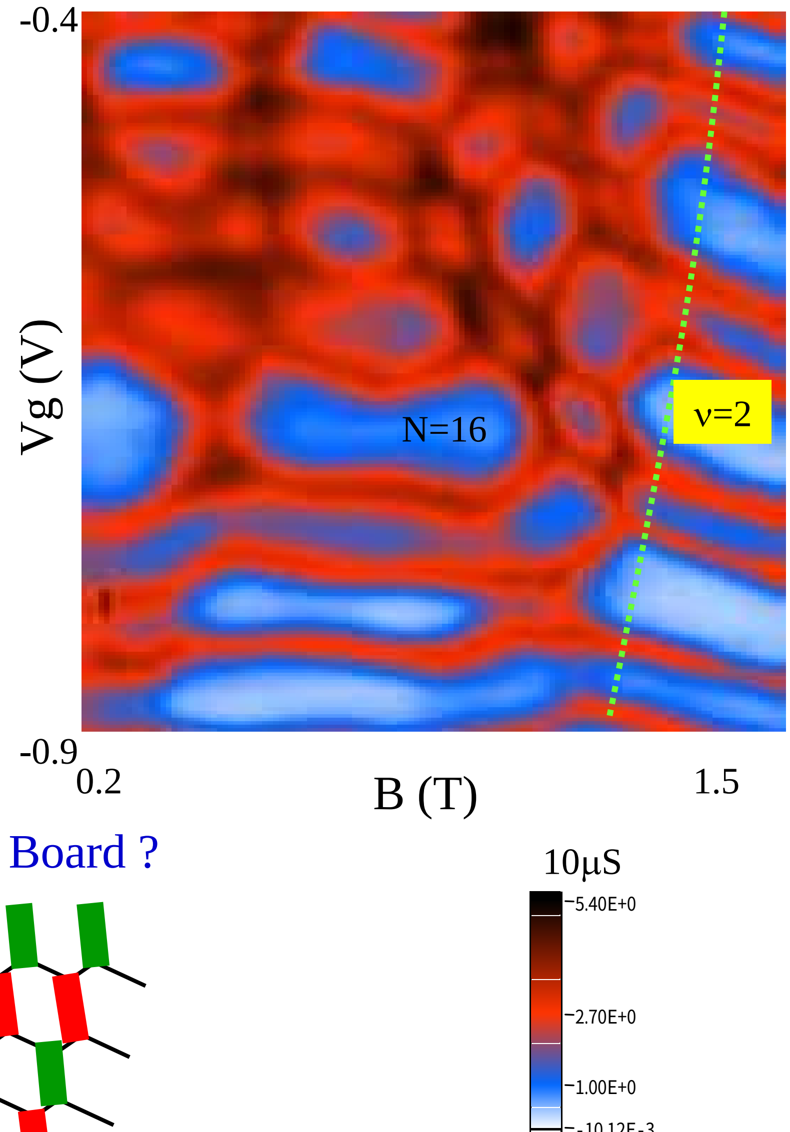
S-T Kondo (even *N*)

D-D Kondo (odd *N*)

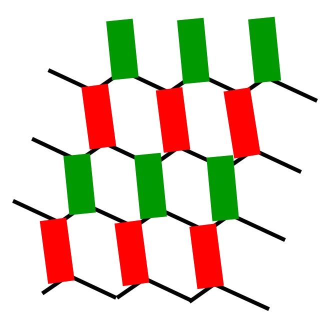
S-T and D-D Kondo at orbital crossings



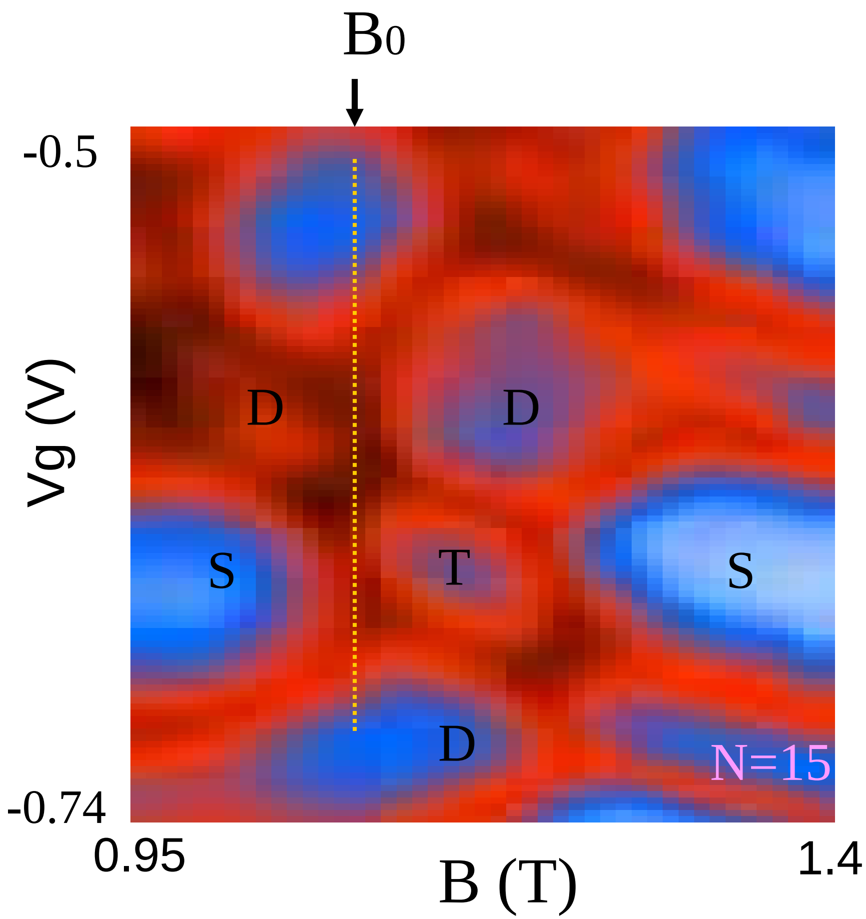


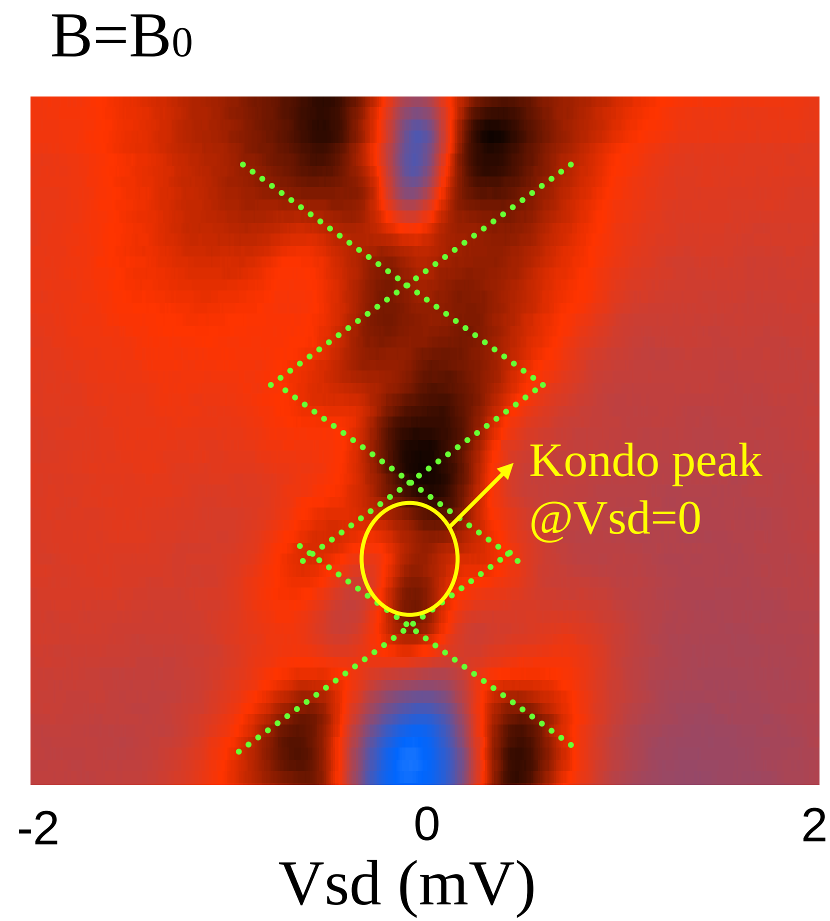


Chess Board ?

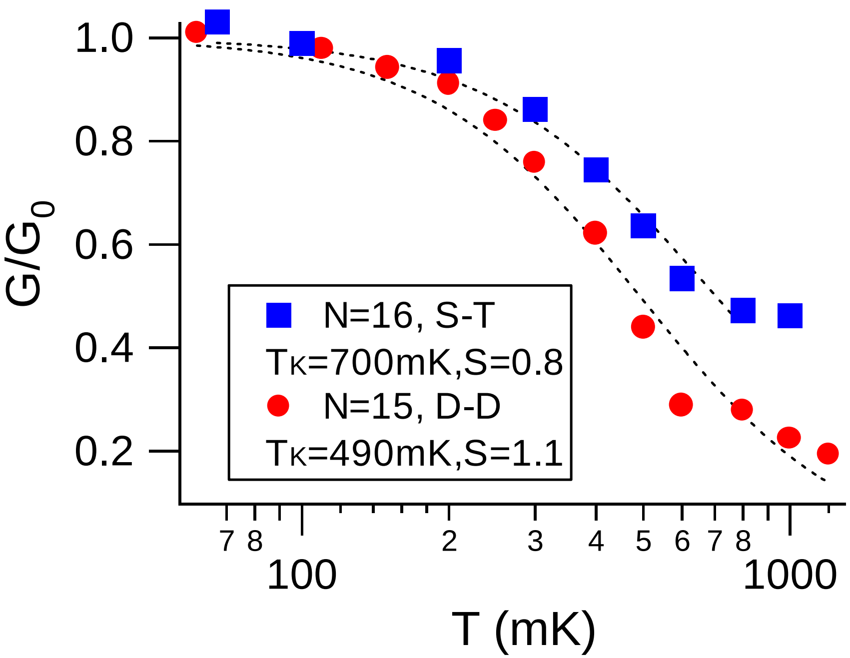


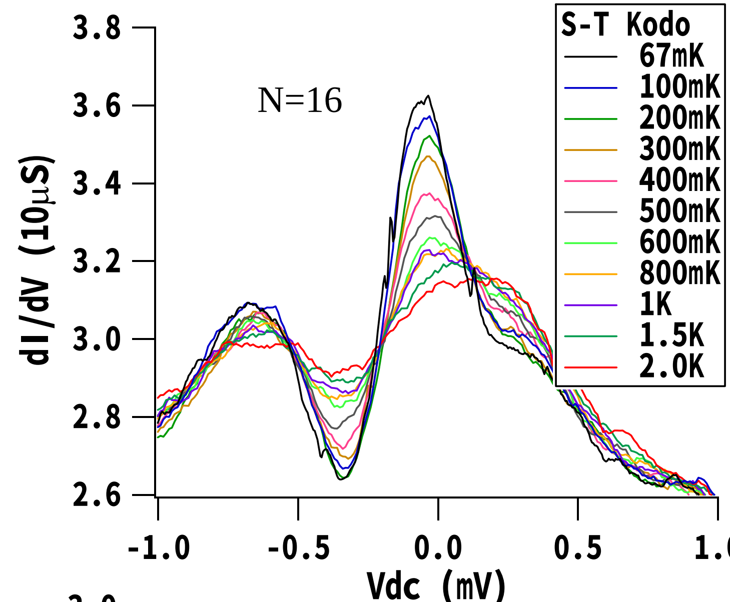
Coulomb diamonds for S-T Kondo

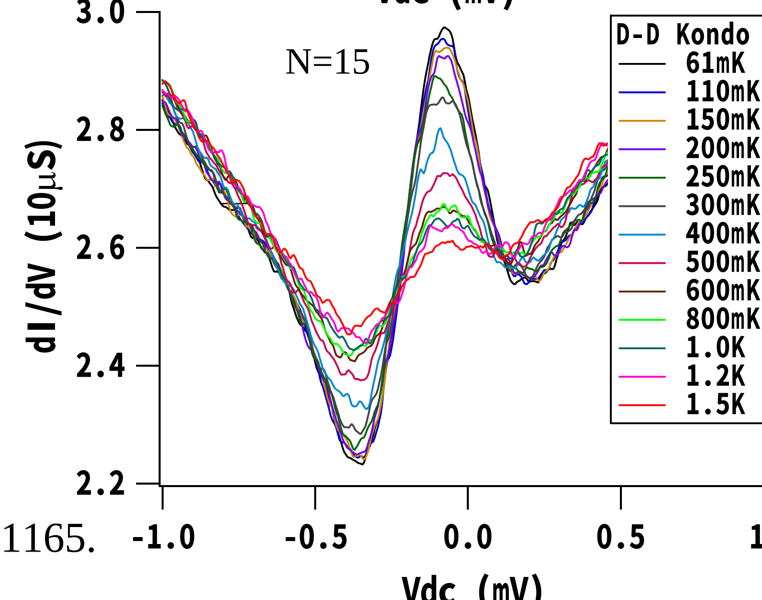




Temperature dependence of S-T and D-D Kondo peak



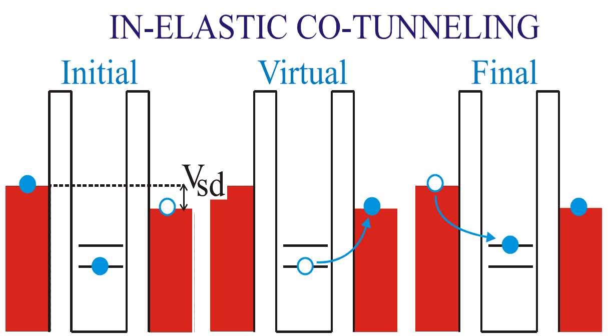


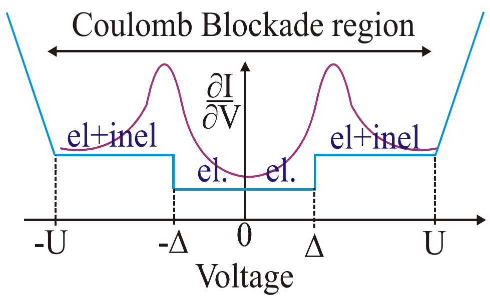


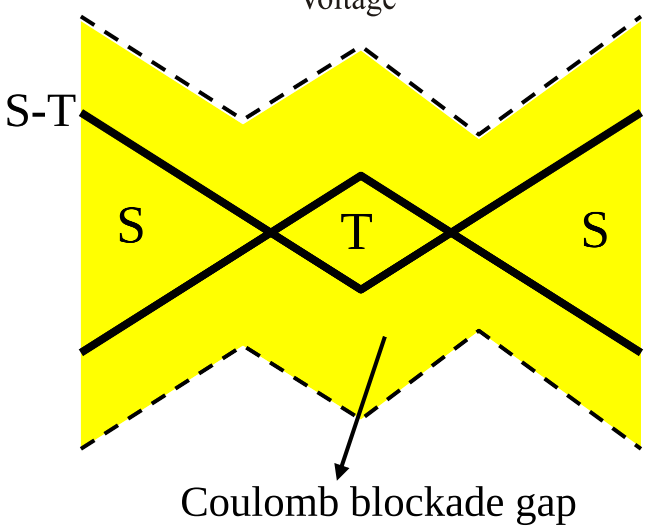
$$G(T) = G_0\left(\frac{T_K'^2}{T^2 + T_K'^2}\right)^s \qquad T_K' = T_K \Big/ \sqrt{2^{1/s} - 1}$$

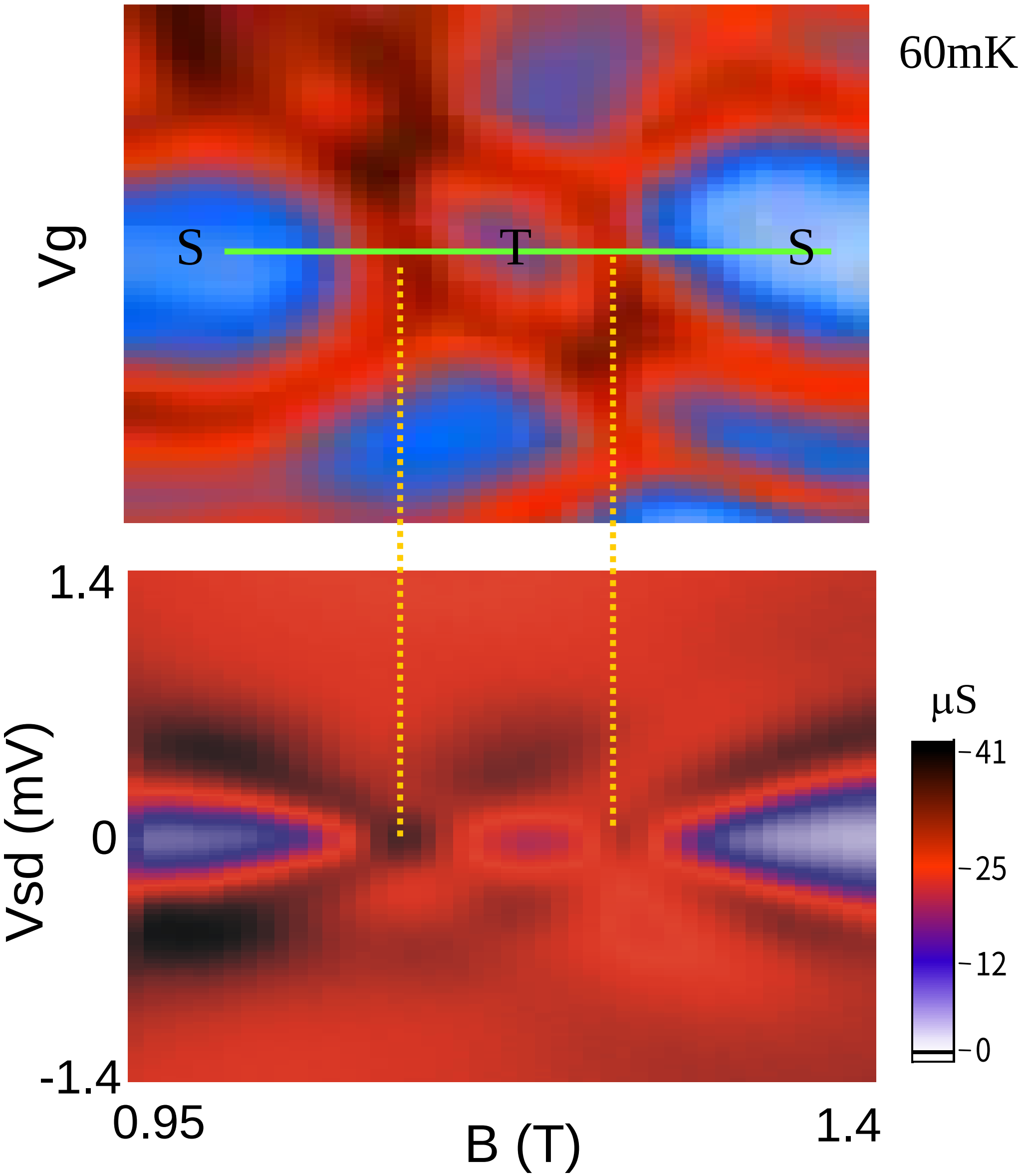
T. A. Costi and A. C. Hewson, Phil. Mag. B65 (1992) 1165.

Kondo peak splitting with S-T degeneracy lifting

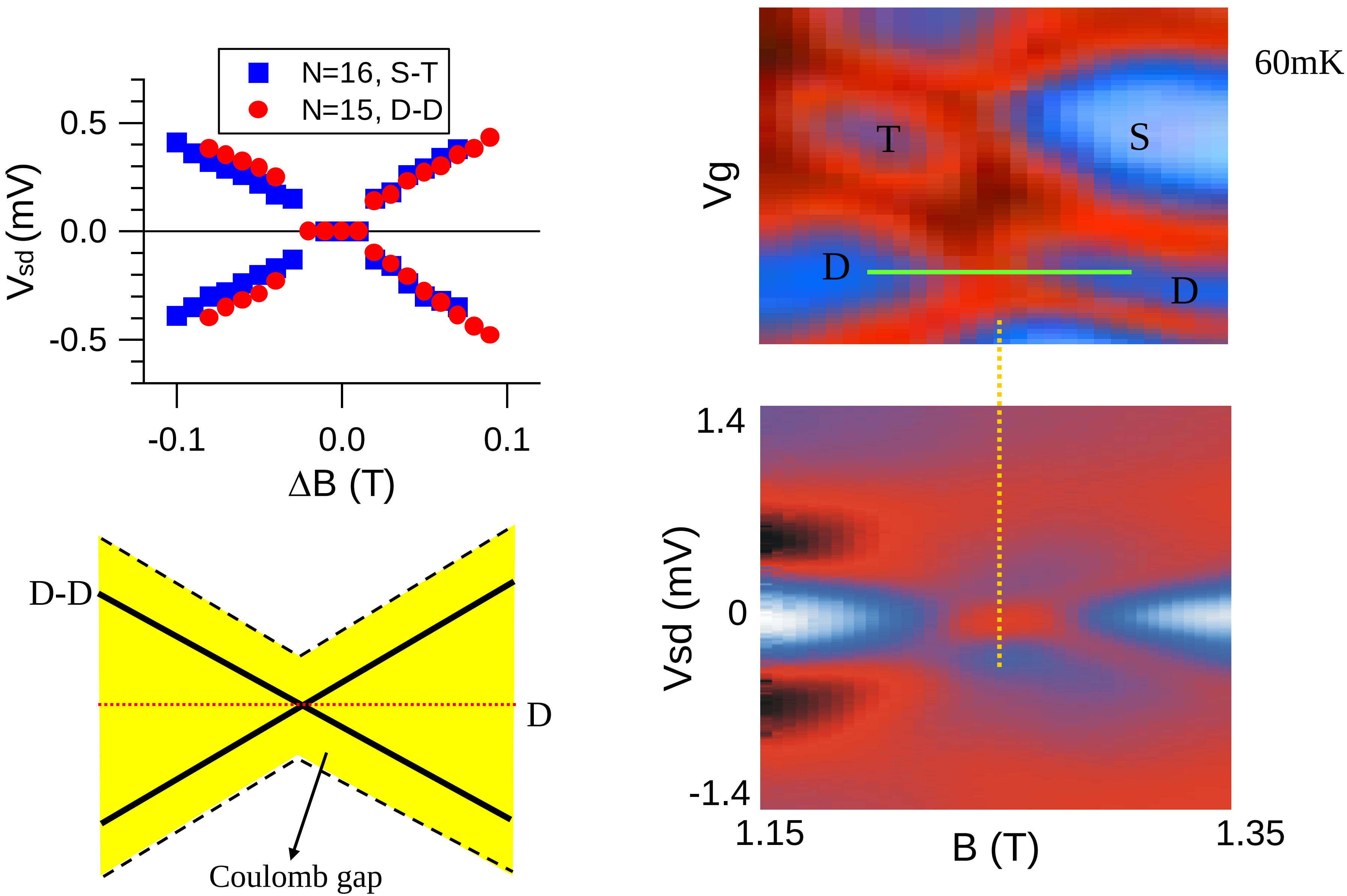




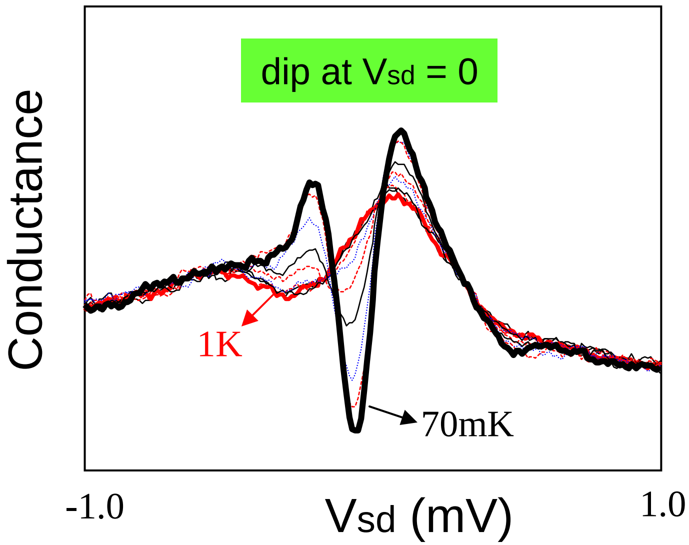




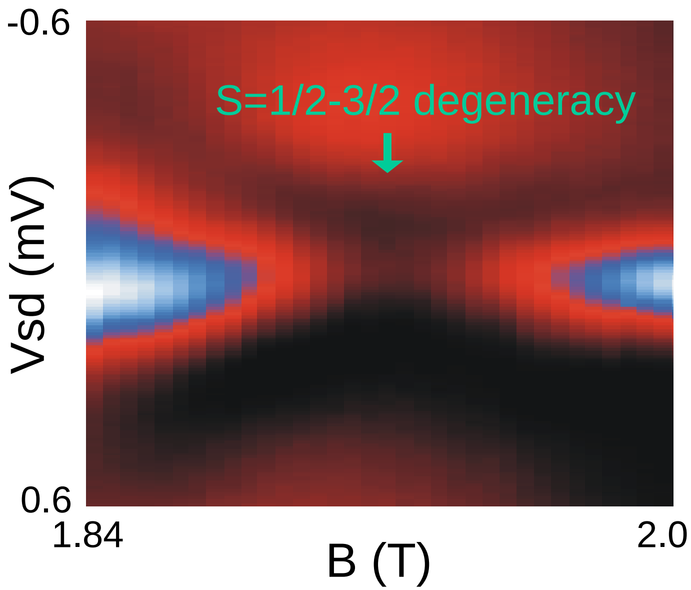
Kondo peak splitting with D-D degeneracy lifting

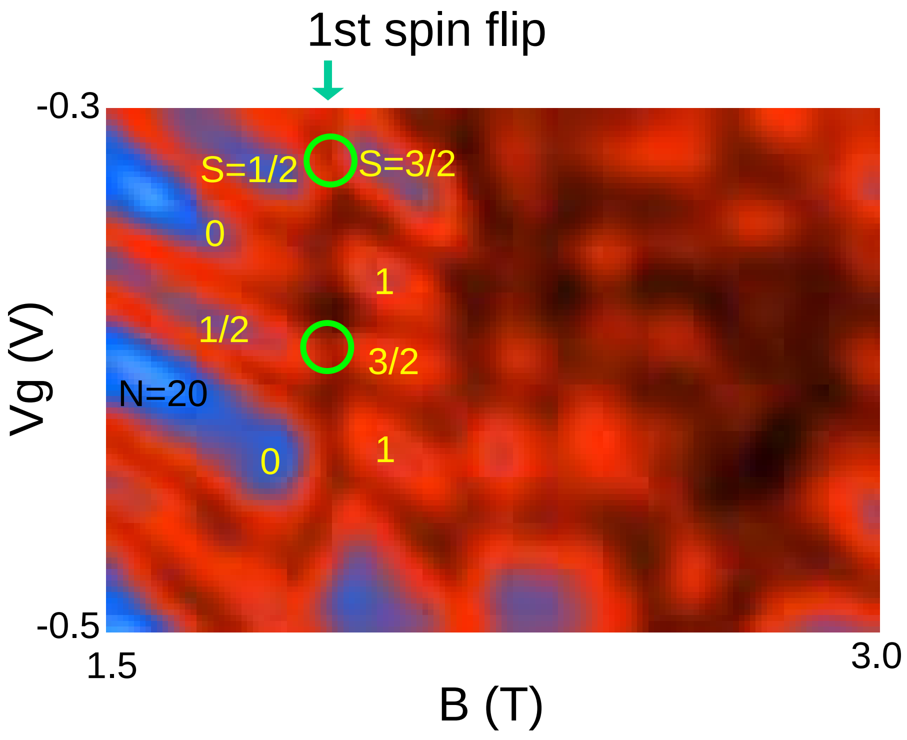


Mysterious behavior at S=1/2 ⇔3/2 degeneracy



← No zero-bias peak in dI/dV??





Summary

Magnetic field induced Kondo effect in a vertical quaytum dot:

- Kondo effect for even *N* ･･･ singlet-triplet
- Kondo effect for odd *N* ･･･ doublet-doublet ←New!

Both give similar Kondo temperature due to four-fold degeneracy