UNIVERSITY OF CAMBRIDGE

Few-atom approach to many-body physics

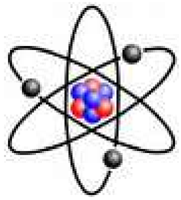
G.J. Conduit and P.O. Bugnion

POB, J. Lofthouse & GJC, Phys. Rev. Lett. **111**, 045301 (2013)

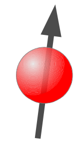
POB & GJC, Phys. Rev. A **87**, 060502(R) (2013)

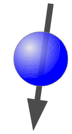
POB & GJC, Phys. Rev. A **88**, 013601 (2013)

Experimental setup



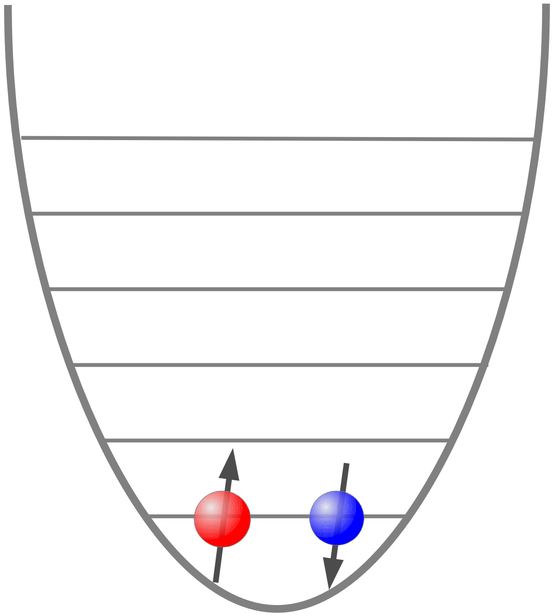
^{6}Li atom

$|F = 1/2, m_F = 1/2\rangle$  Up spin electron

$|F = 1/2, m_F = -1/2\rangle$  Down spin electron

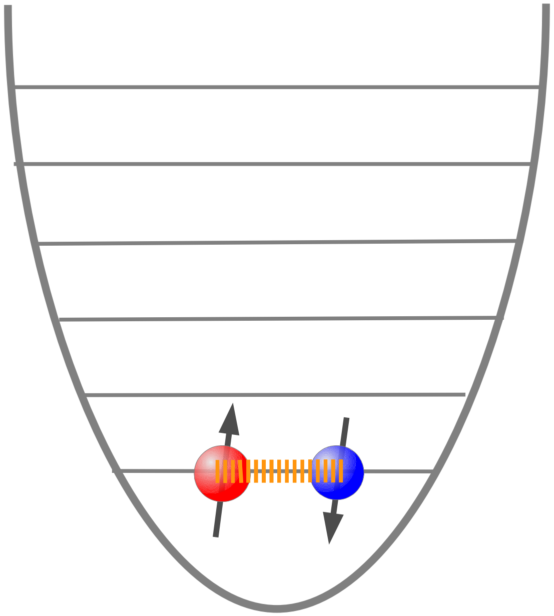
$$\hat{H} = -\frac{\nabla^2}{2} + g n_{\uparrow}(\vec{r}) n_{\downarrow}(\vec{r})$$

Two distinguishable fermions

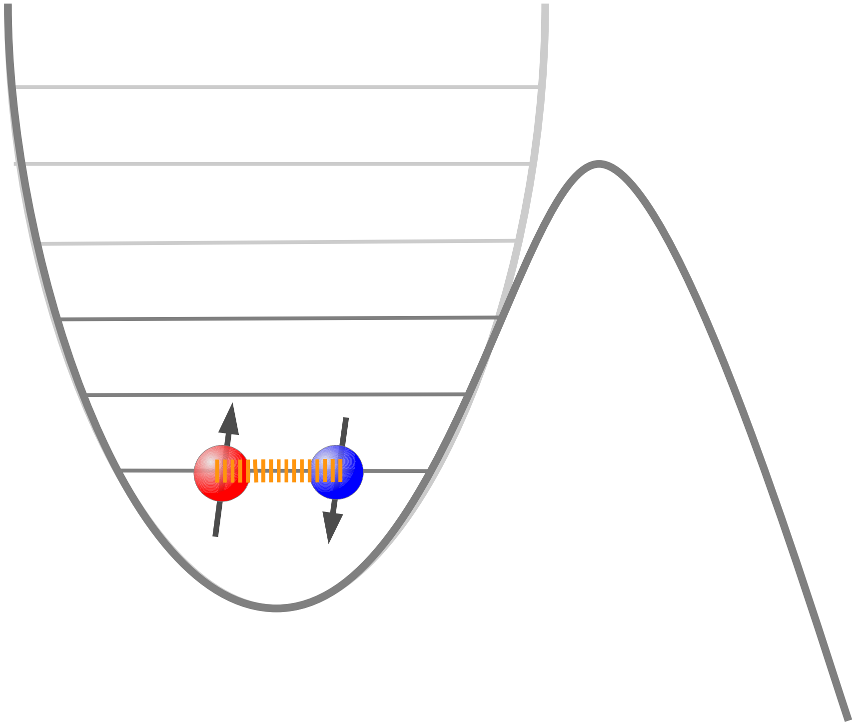


G. Zürn *et al*. PRL 108 075303 (2012)

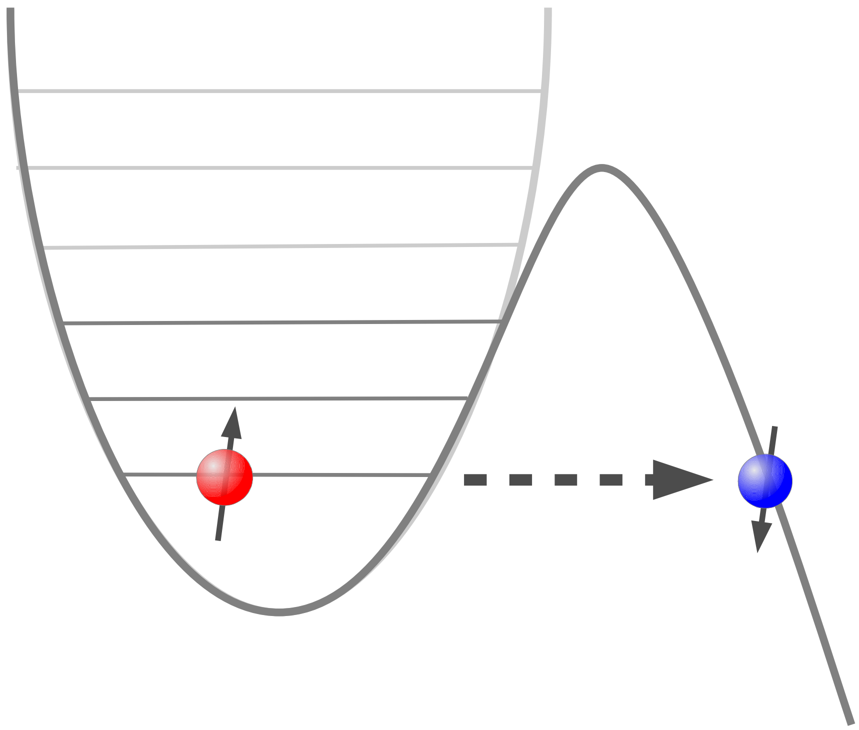
Two distinguishable fermions



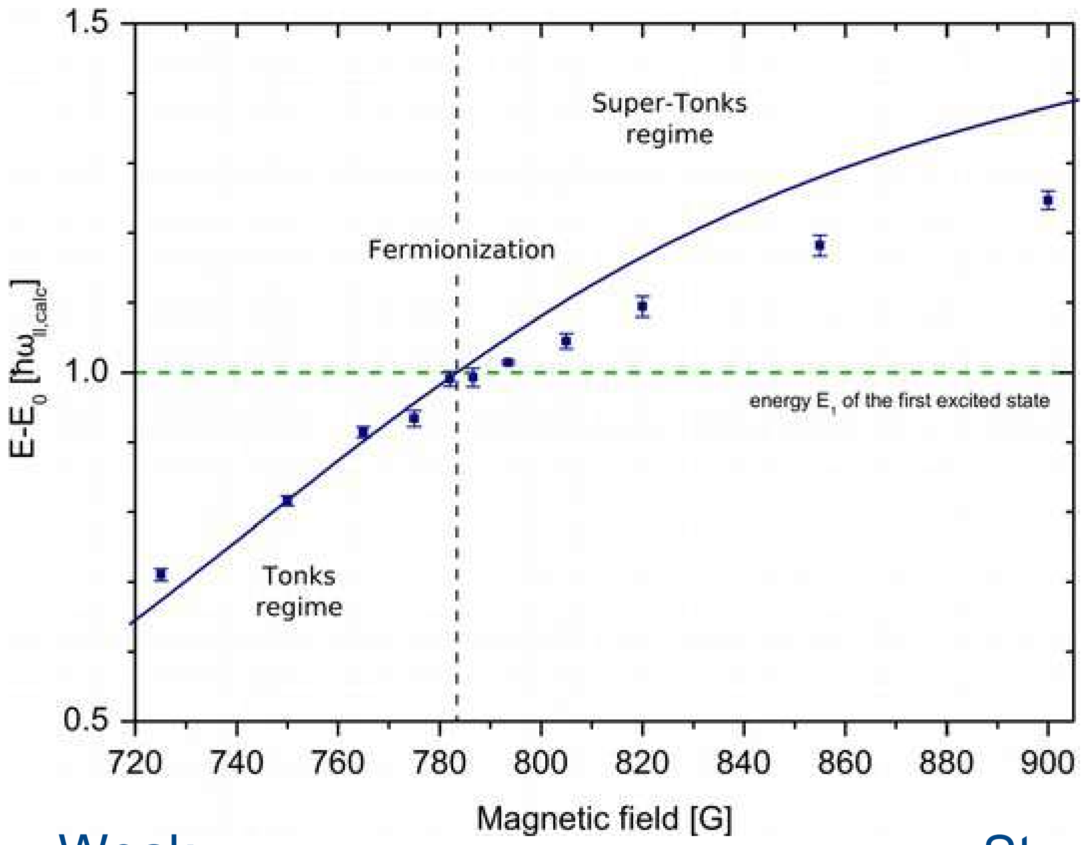
Two distinguishable fermions

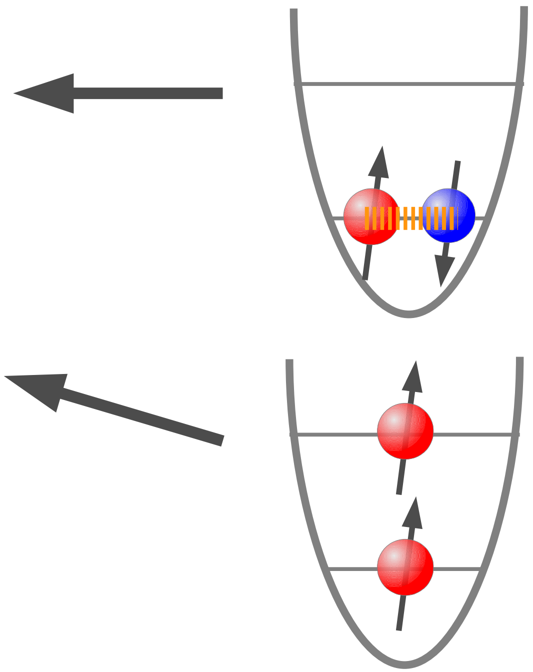


Two distinguishable fermions



Energy of states

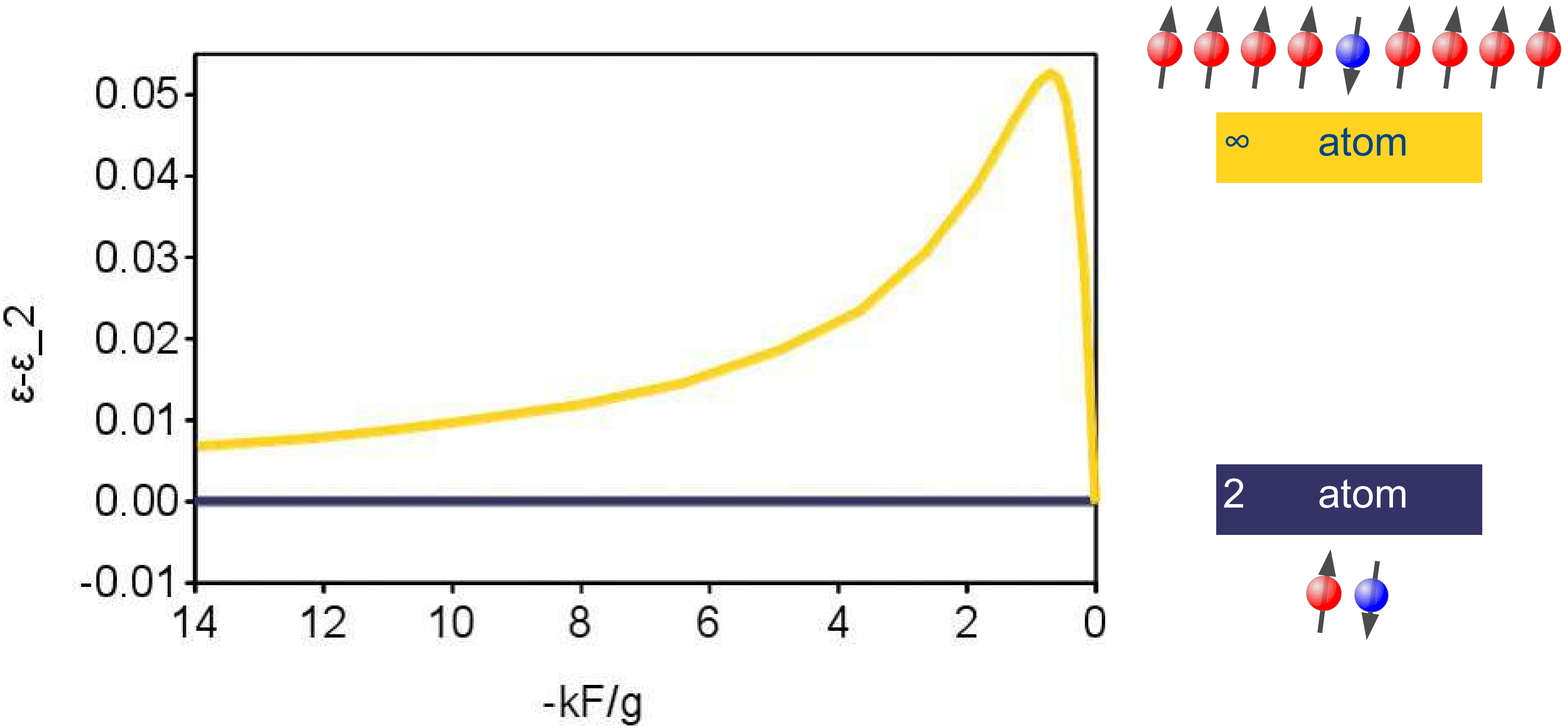




Weak repulsion

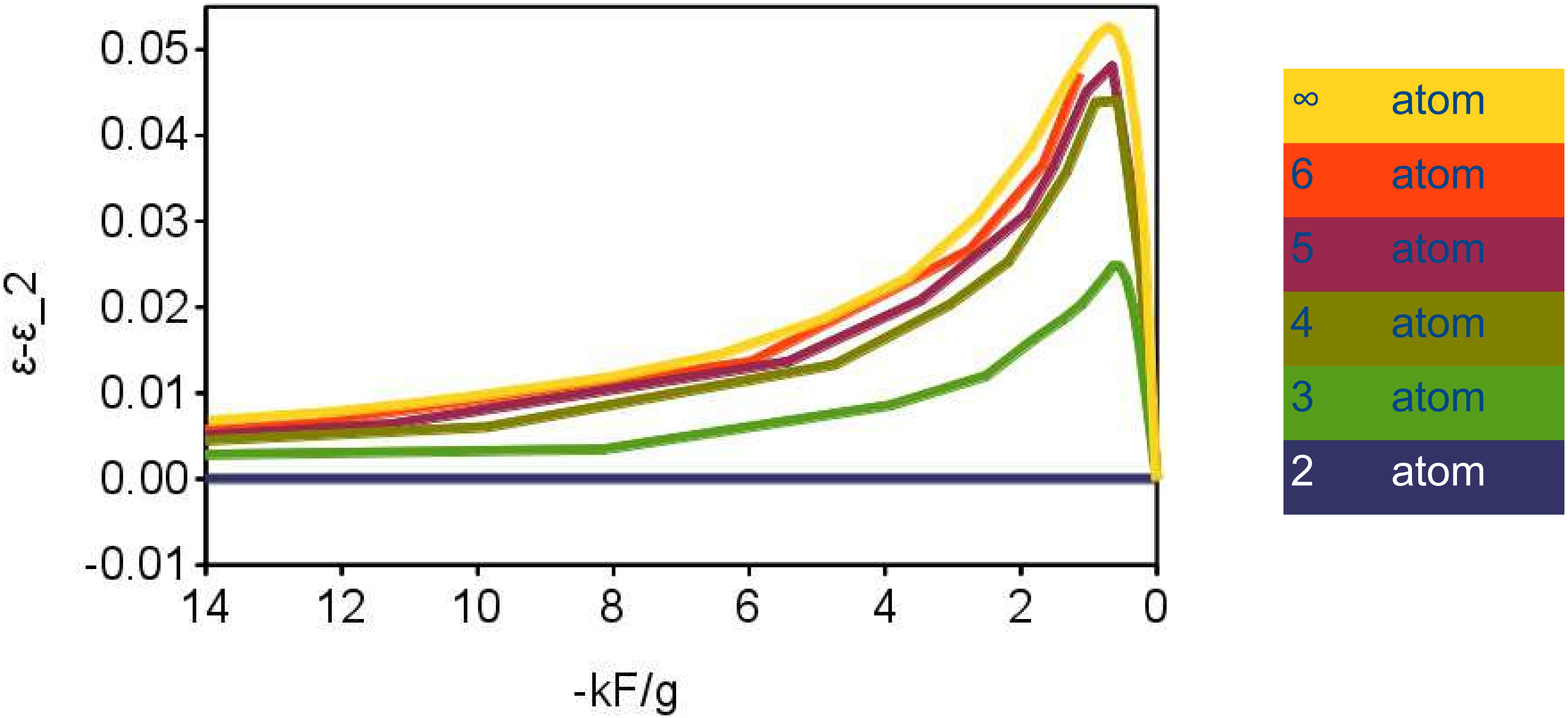
Strong repulsion

Polaron state



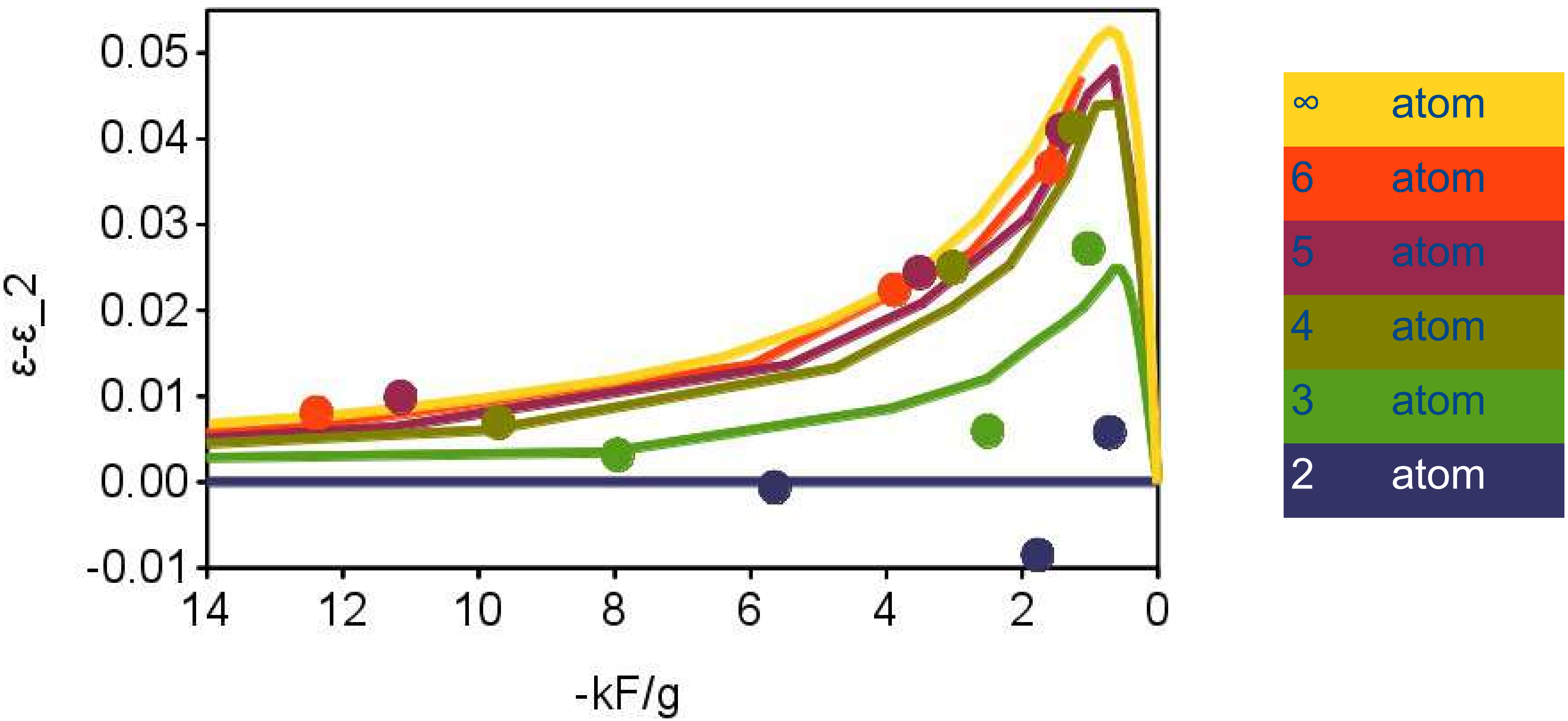
J.B. McGuire, J. Math. Phys. **6**, 432 (1965)

Polaron state



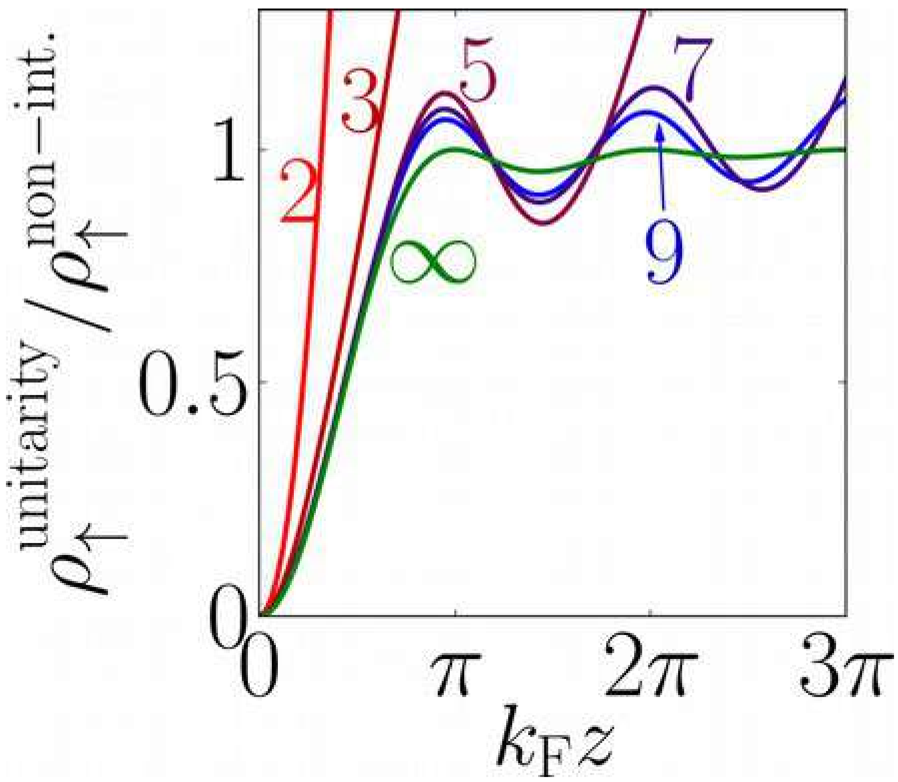
P.O. Bugnion & G.J. Conduit Phys. Rev. A **87**, 060502(R) (2013)

Polaron state



A. Wenz *et al.*, arXiv:1307.3443

Polaron state



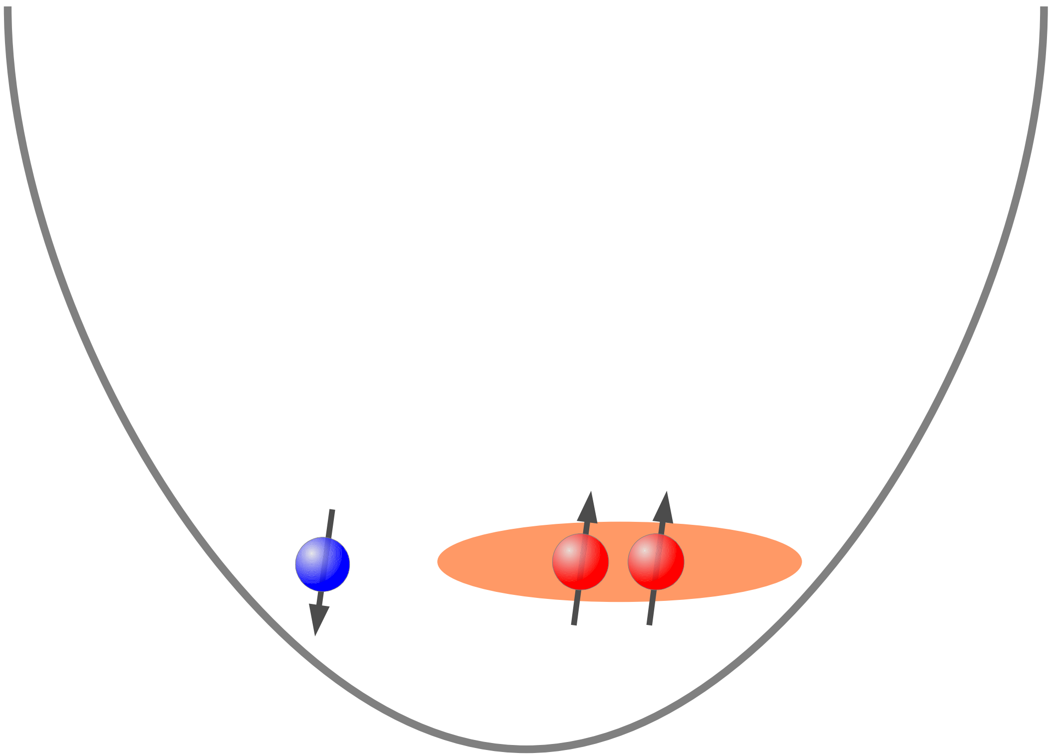
Strongly correlated physics

Repulsive interactions →	Ferromagnetic correlations
Attractive interactions →	BCS pairing / FFLO
Double well →	Exchange interactions
Zero dimensional →	Hund's rules
Perturbed trap →	Rabi / Josephson oscillations

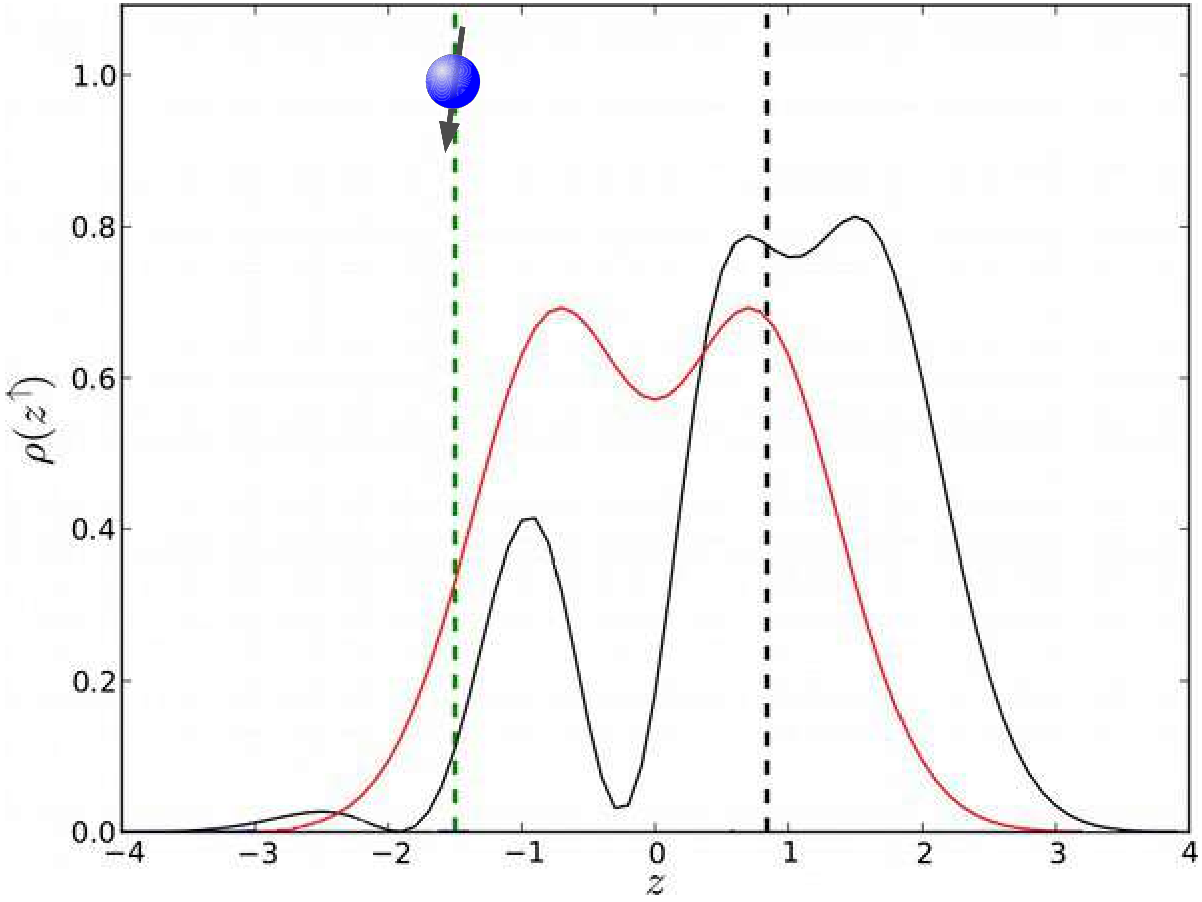
Stoner Hamiltonian

$$\hat{H} = -\frac{\nabla^2}{2} + g n_{\uparrow}(\vec{r}) n_{\downarrow}(\vec{r}) + V(\vec{r})$$

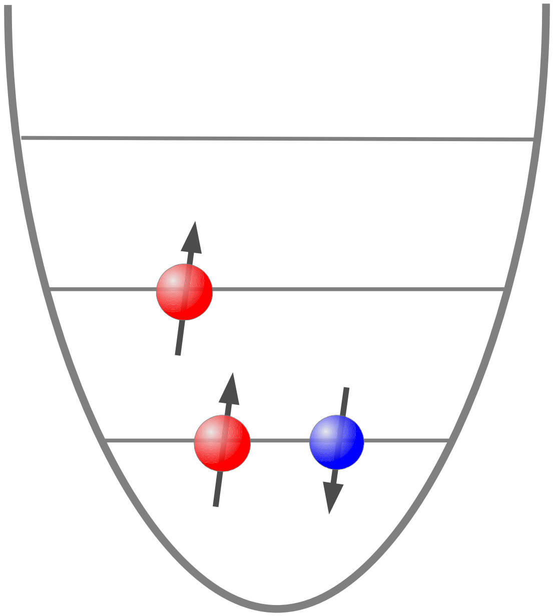
Density profiles



Density profiles



Polaron state



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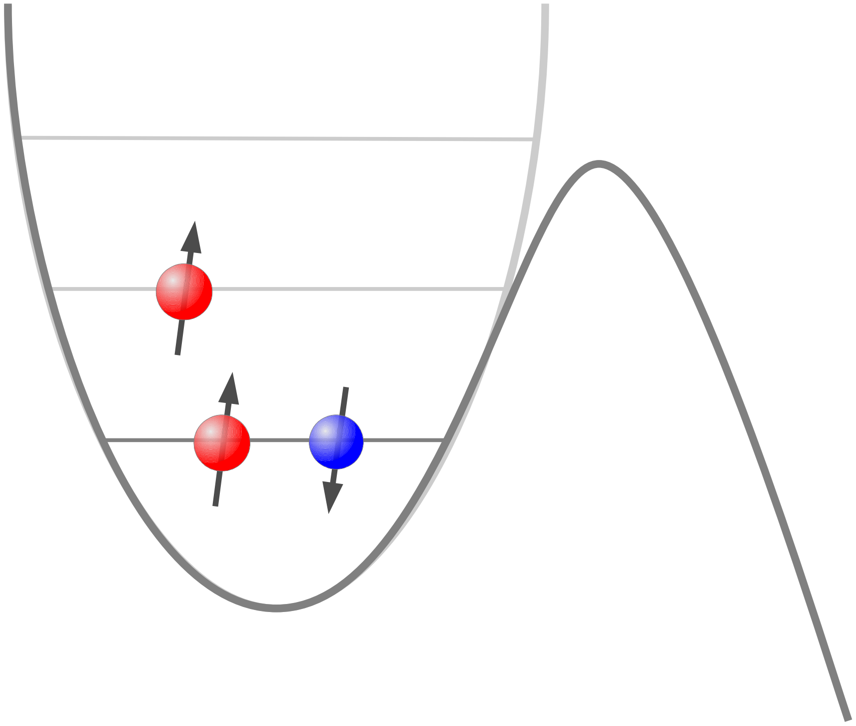
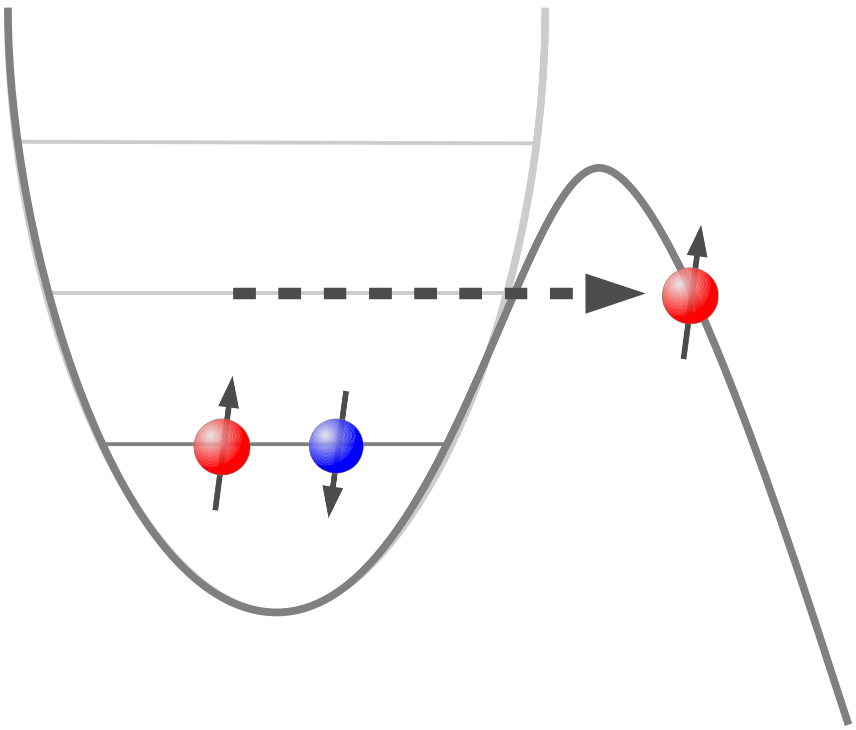
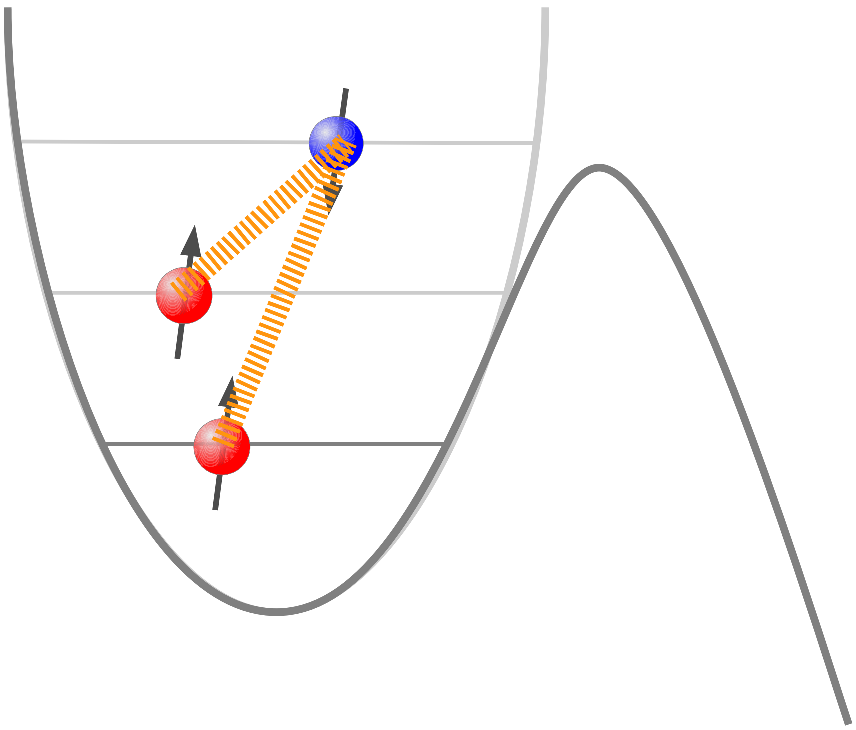


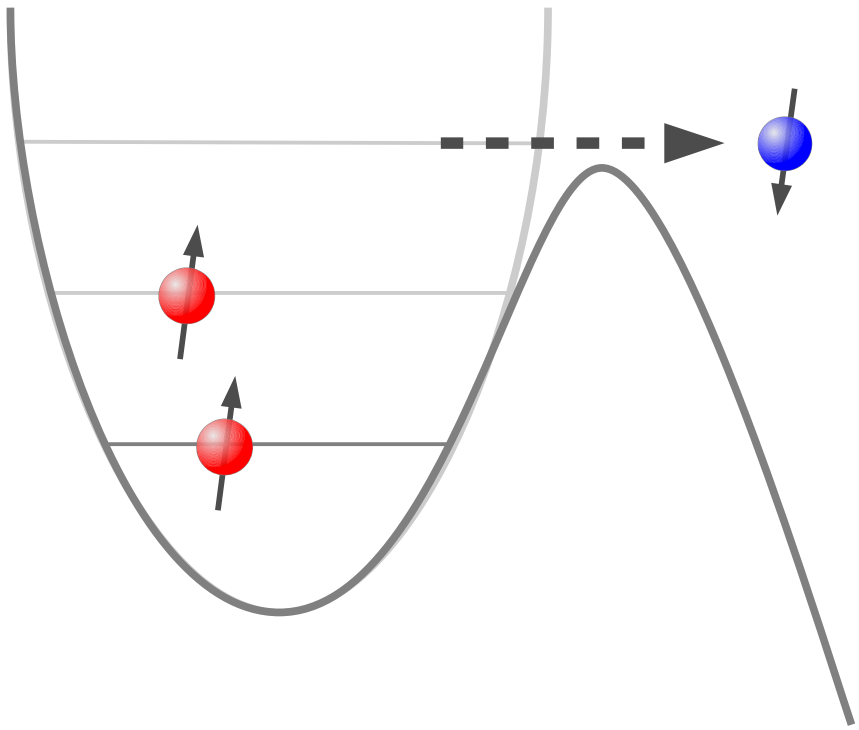
Polaron state



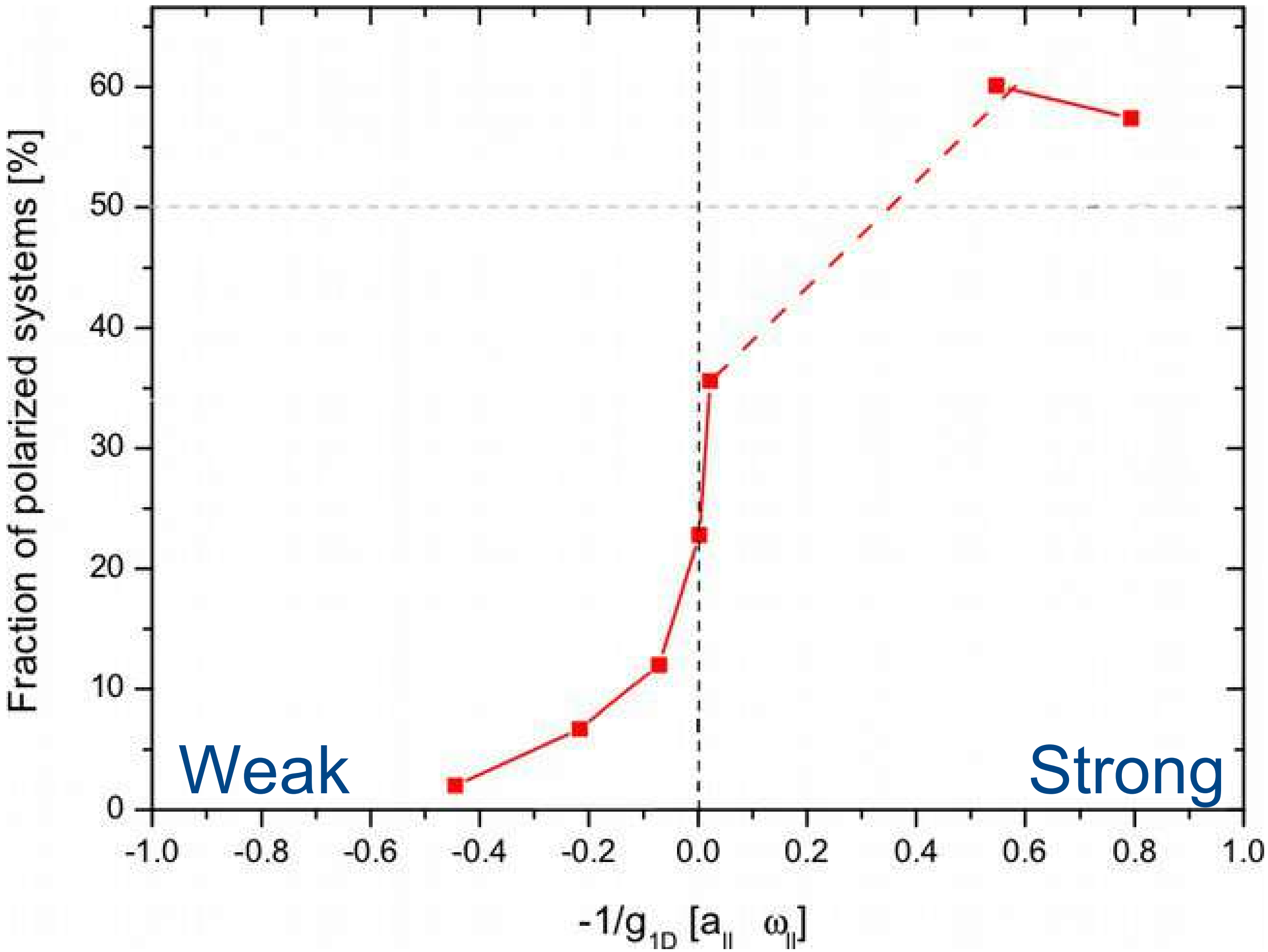
Polaron state



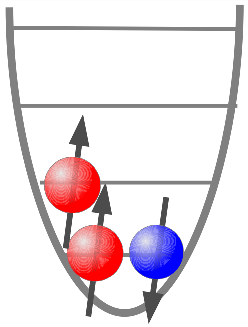
Polaron state



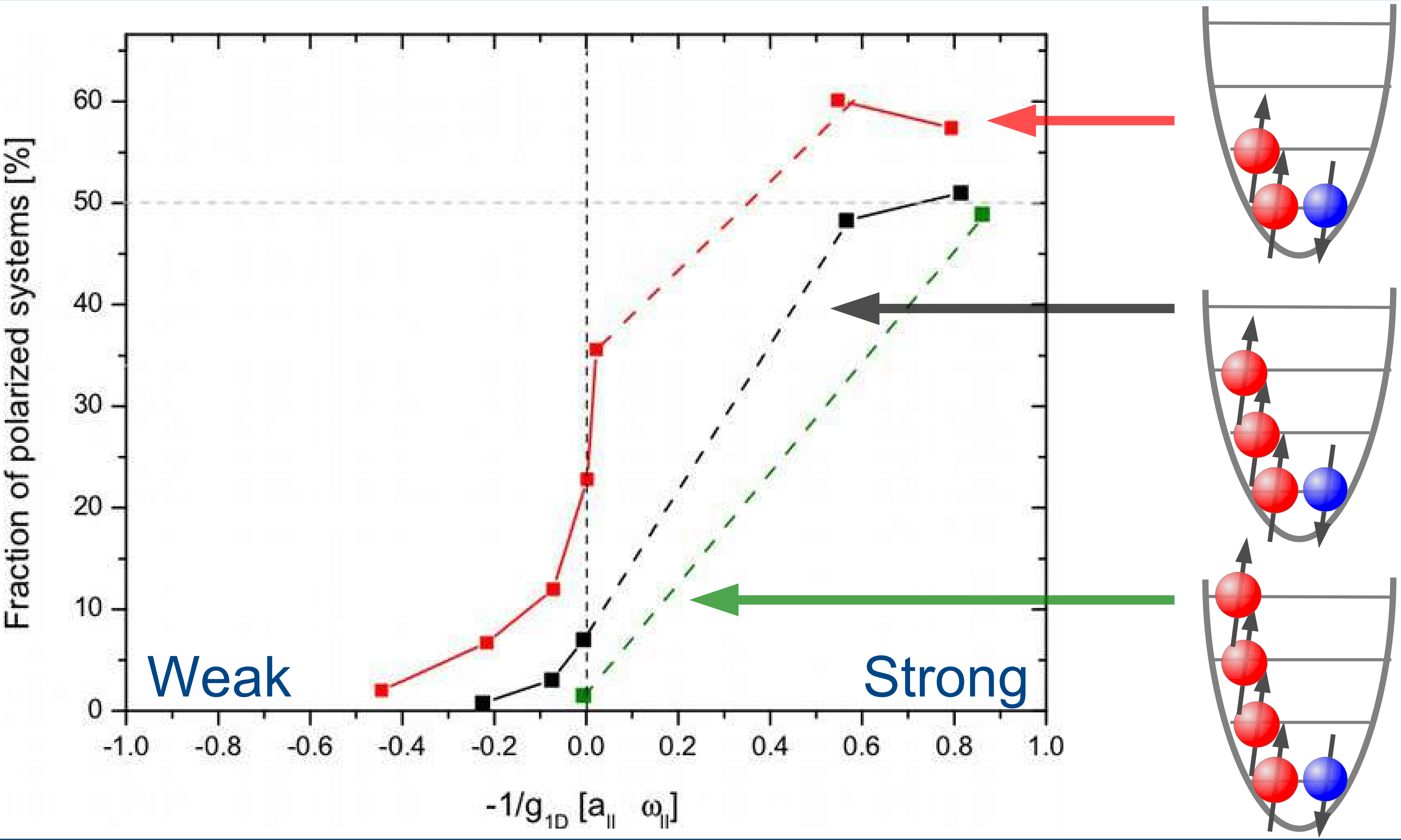
Loss region



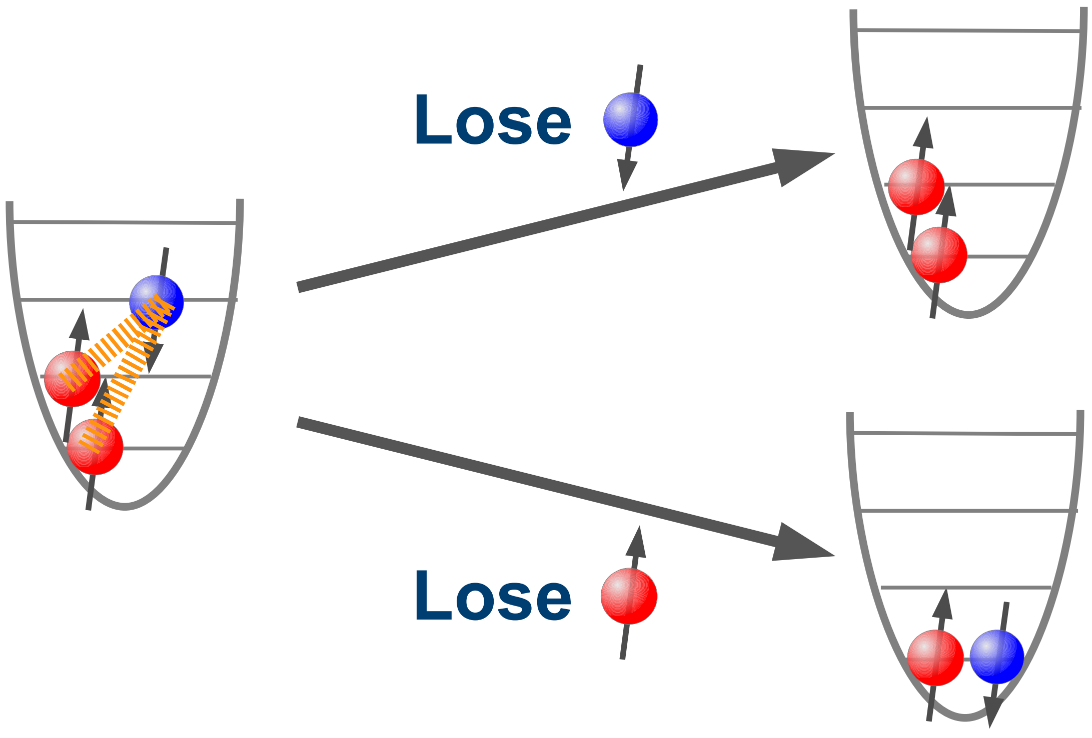
Fraction of polarized systems [%]
0
10
20
30
40
50
60
-1.0
-0.8
-0.6
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8
1.0
-1/g1D [a|| ω||]
Weak
Strong



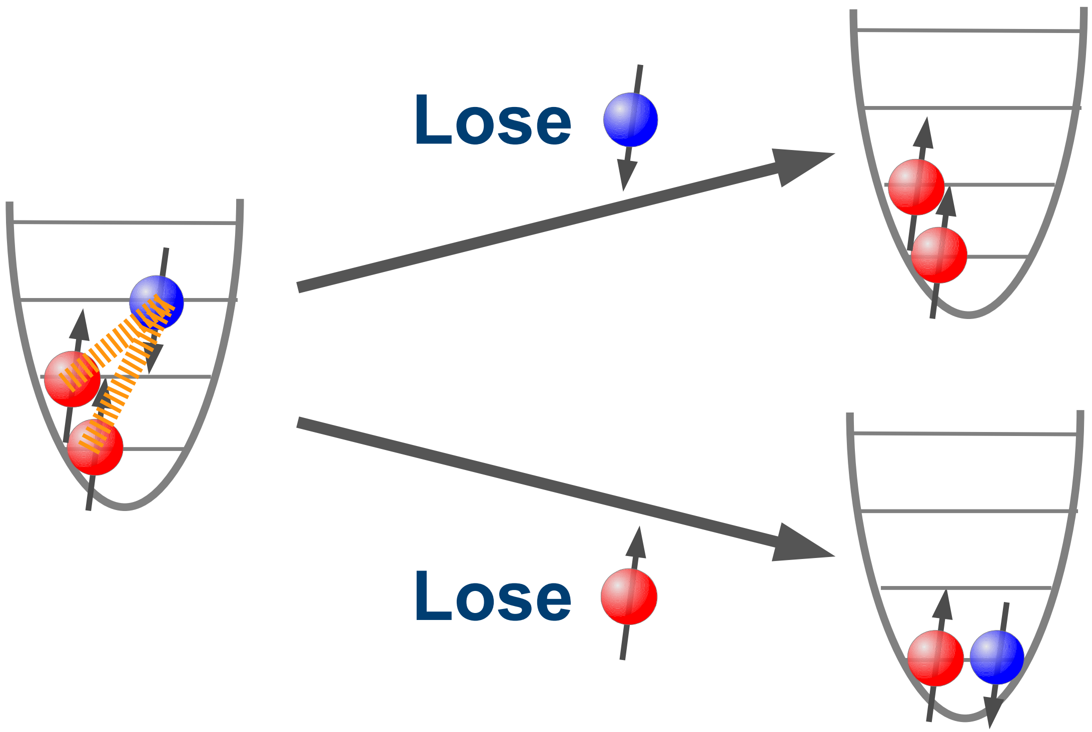
Tunneling probability



Why probability of ½?



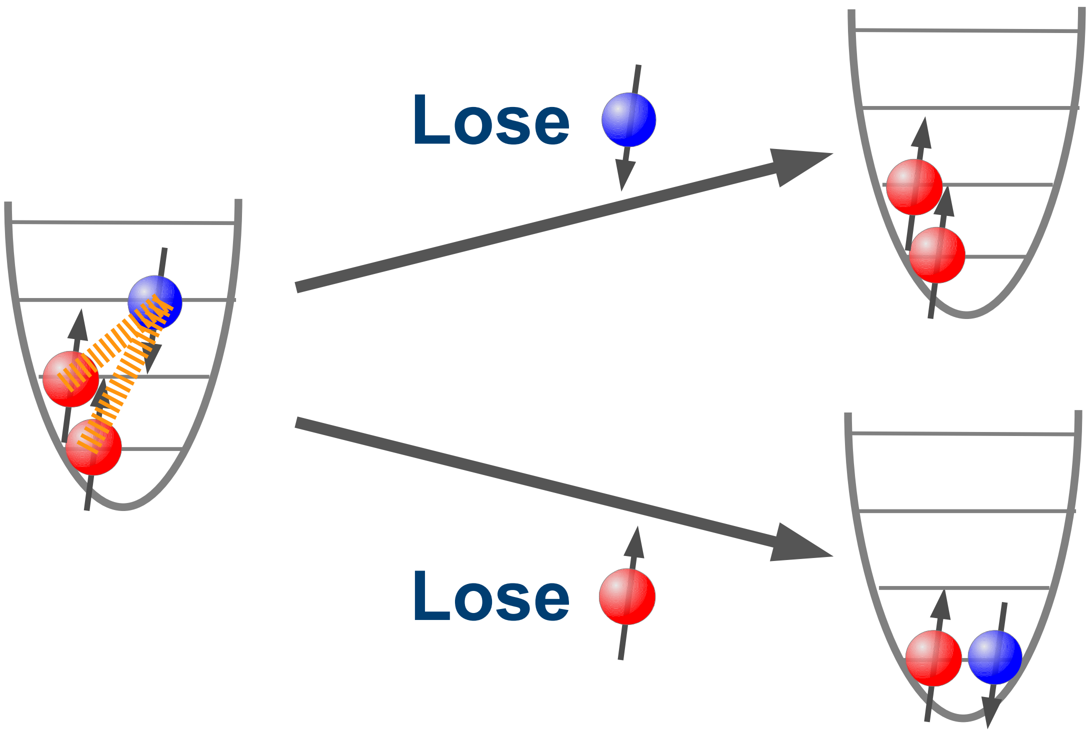
Why probability of ½?



$|\uparrow\uparrow\rangle$

Ferro

Why probability of ½?



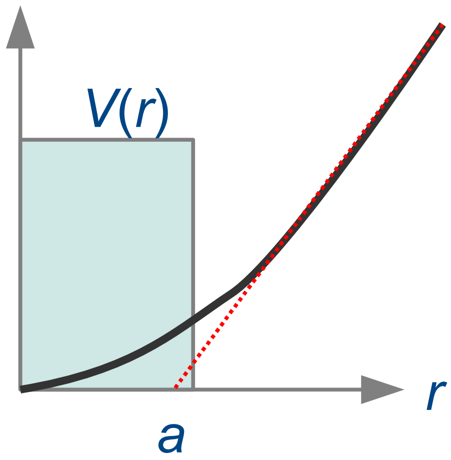
$|\uparrow\uparrow\rangle$ **Ferro**

$|\uparrow\downarrow\rangle + |\downarrow\uparrow\rangle$ **Ferro**

$|\uparrow\downarrow\rangle - |\downarrow\uparrow\rangle$ **Para**

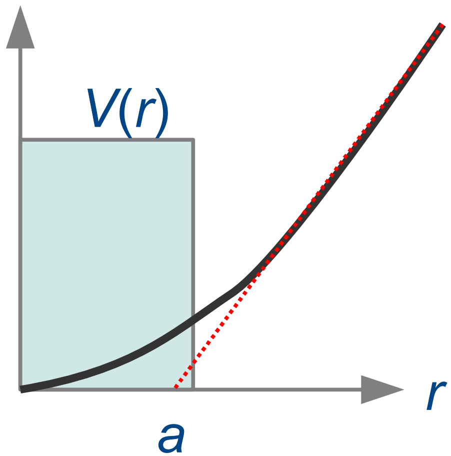
Two-atom scattering

Repulsive

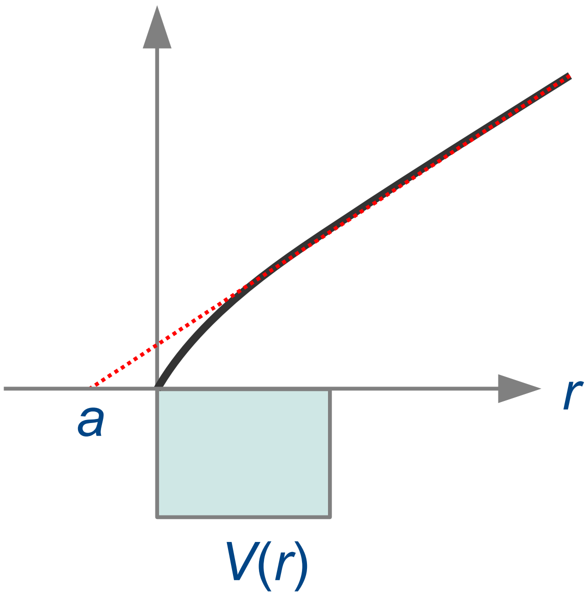


Two-atom scattering

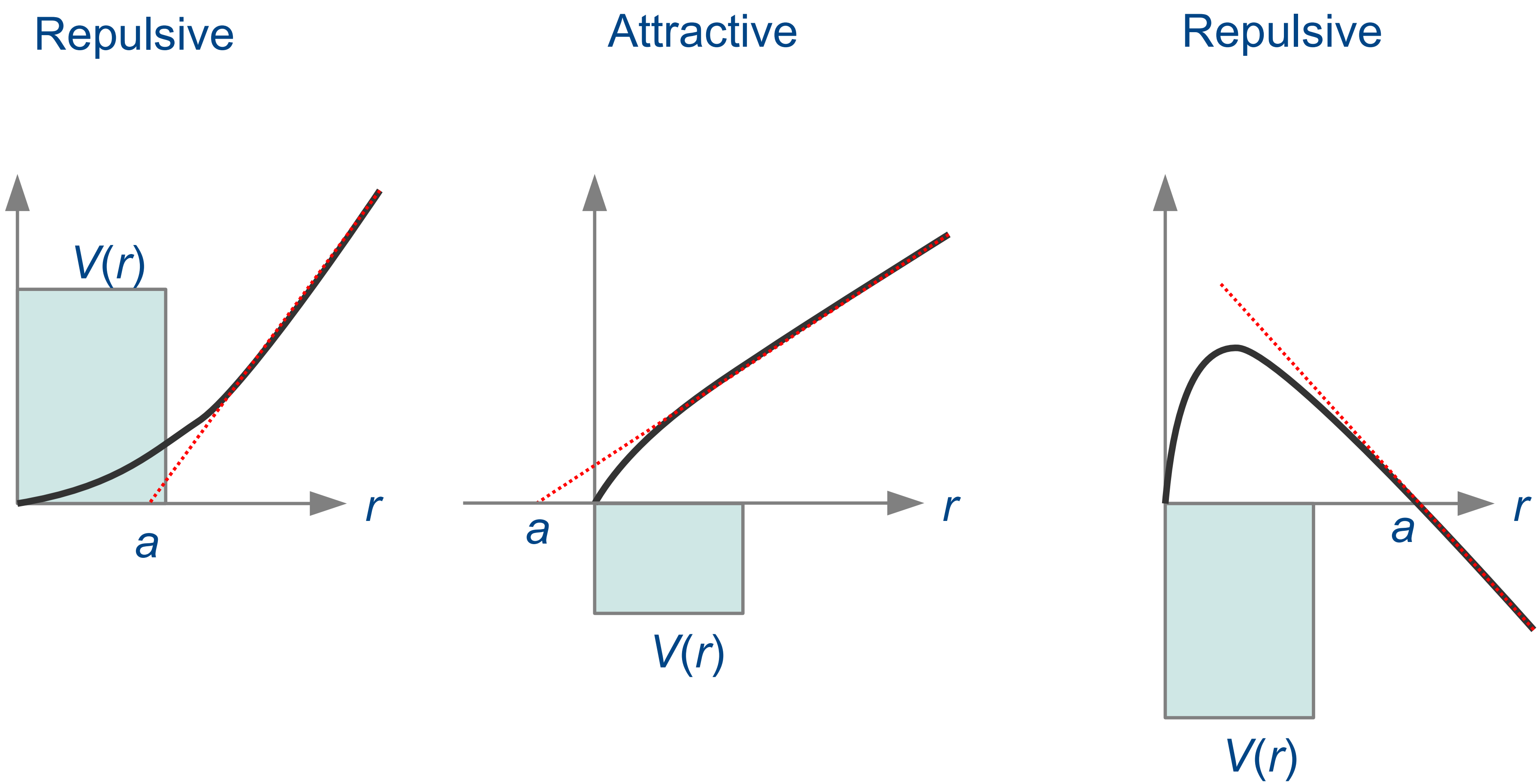
Repulsive



Attractive

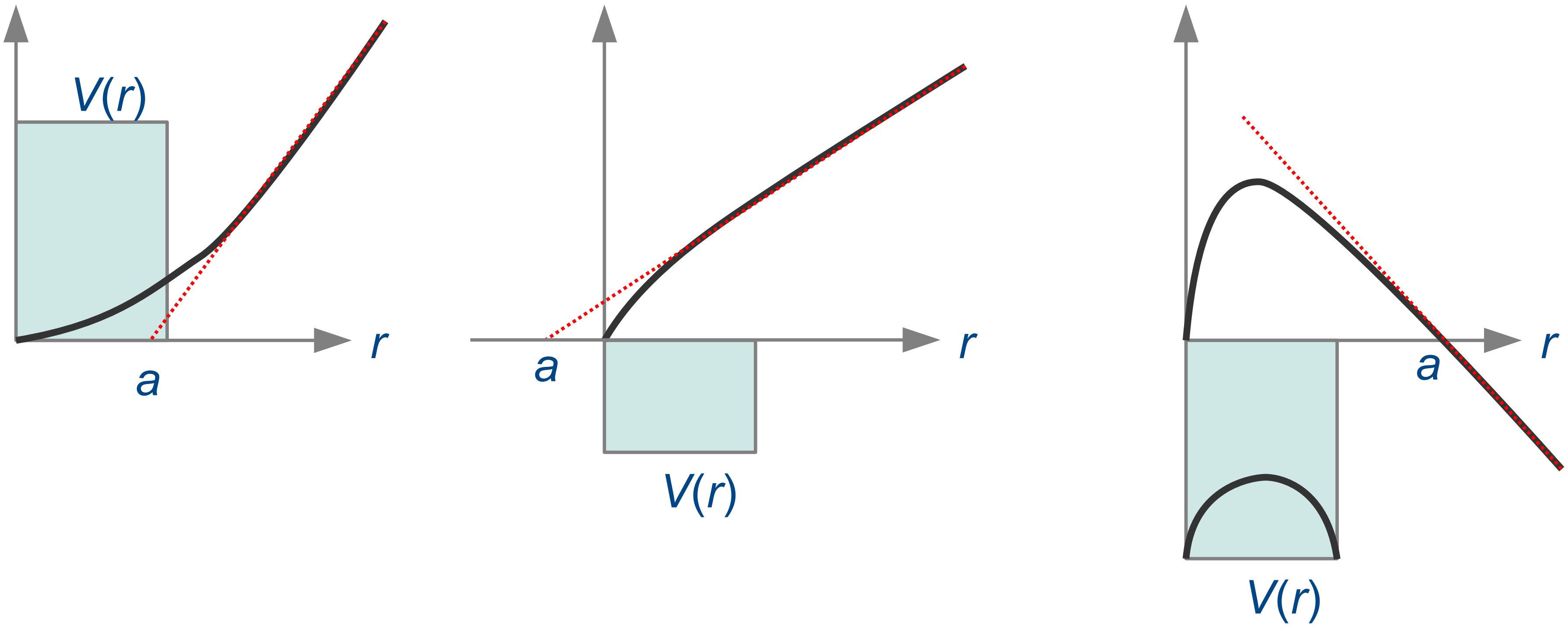


Two-atom scattering

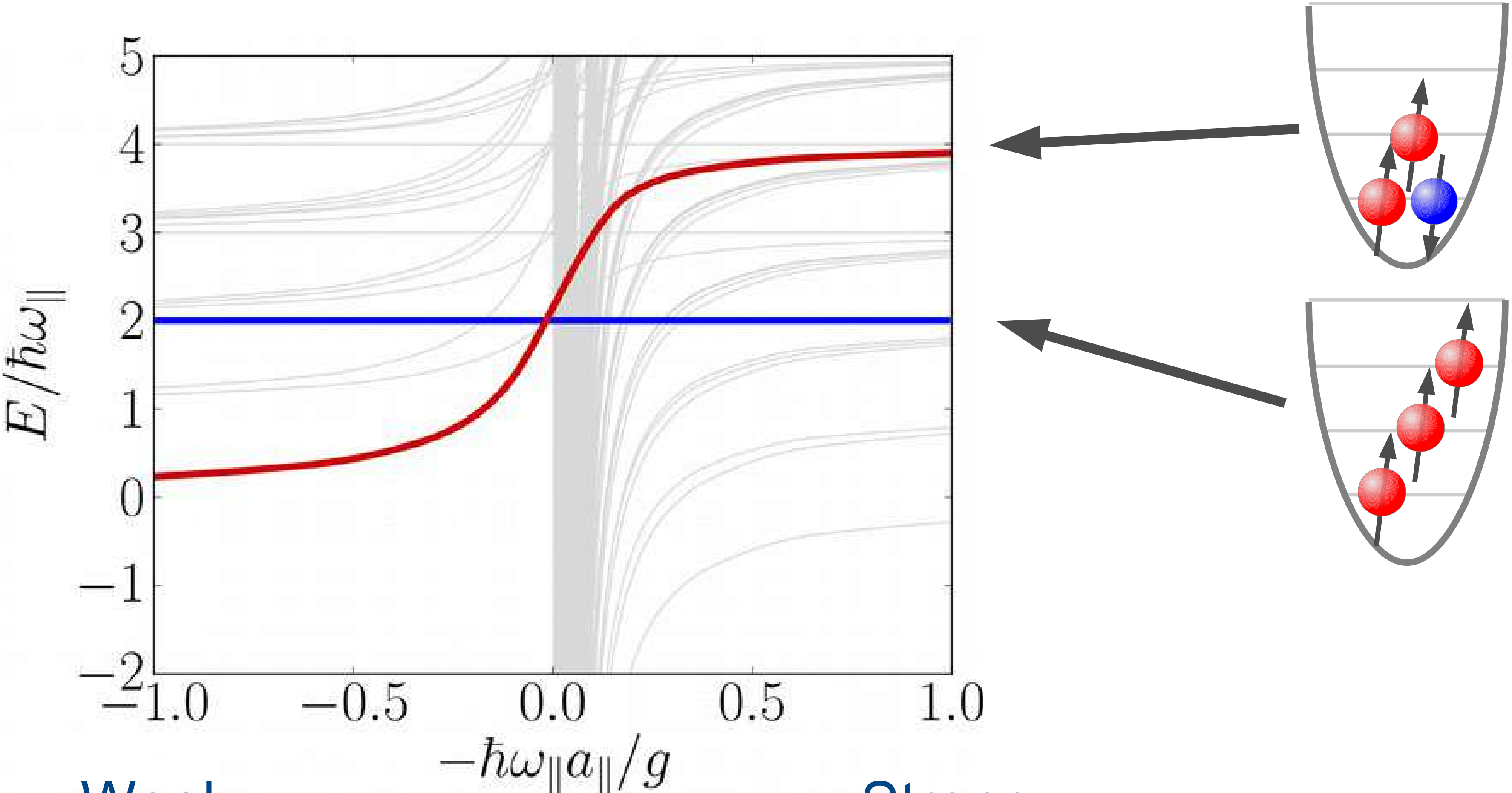


Two-atom scattering

Repulsive — Attractive — Repulsive



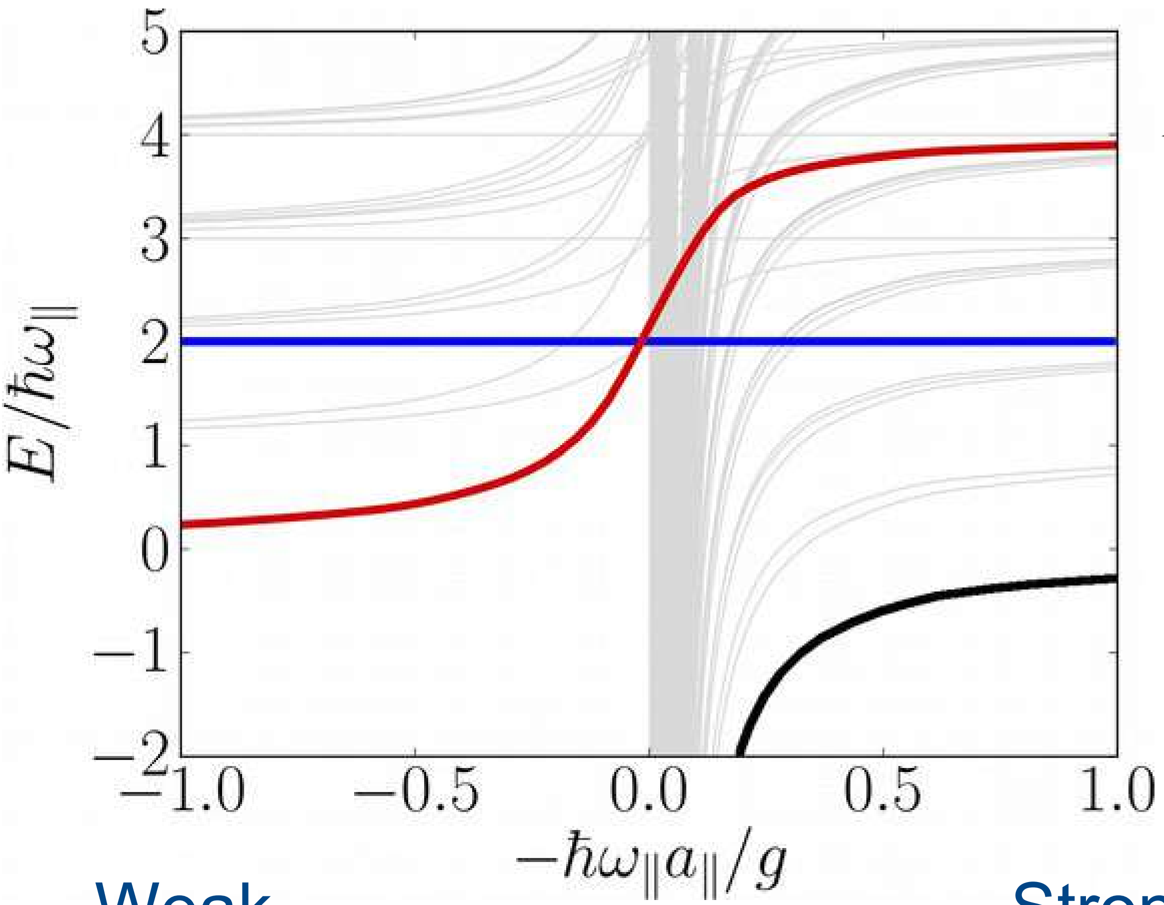
Three-atom bound state

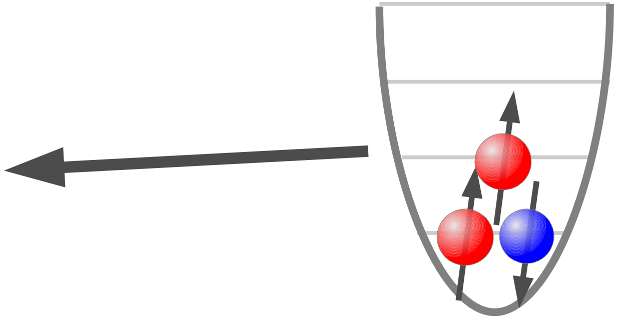


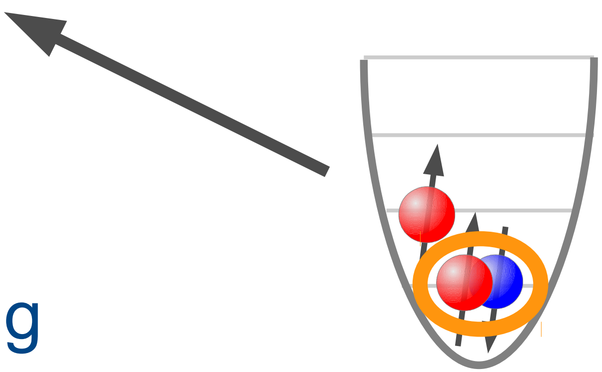
Weak

Strong

Three-atom bound state



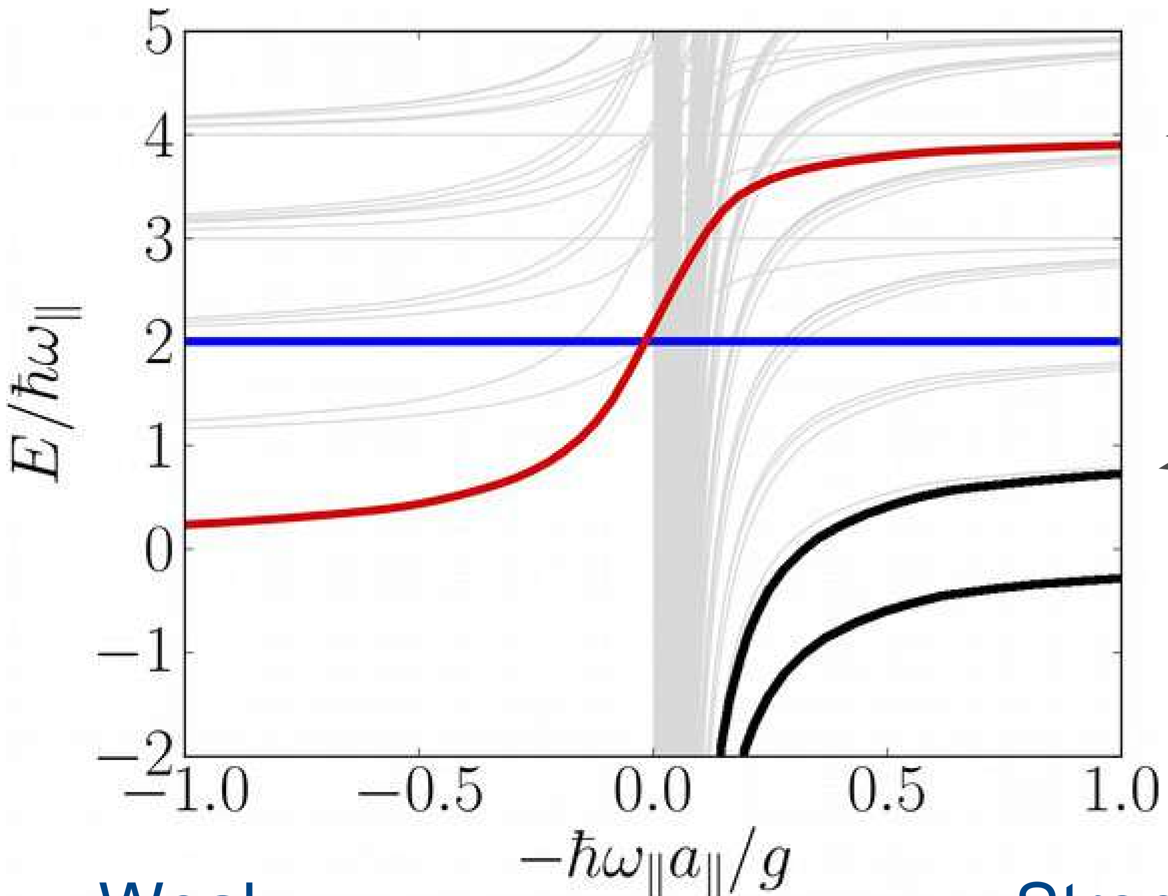




Weak

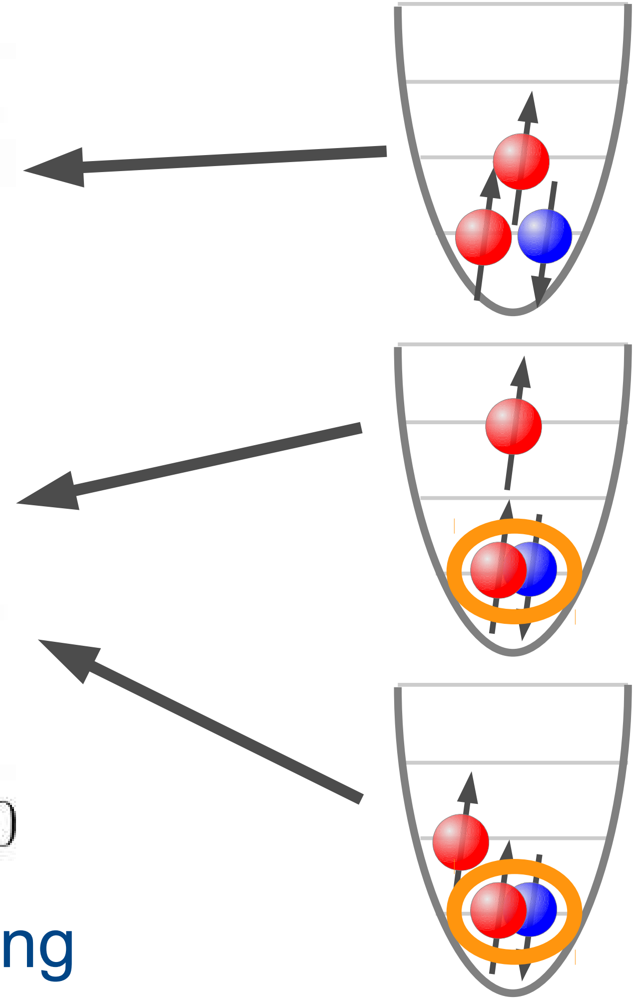
Strong

Three-atom bound state

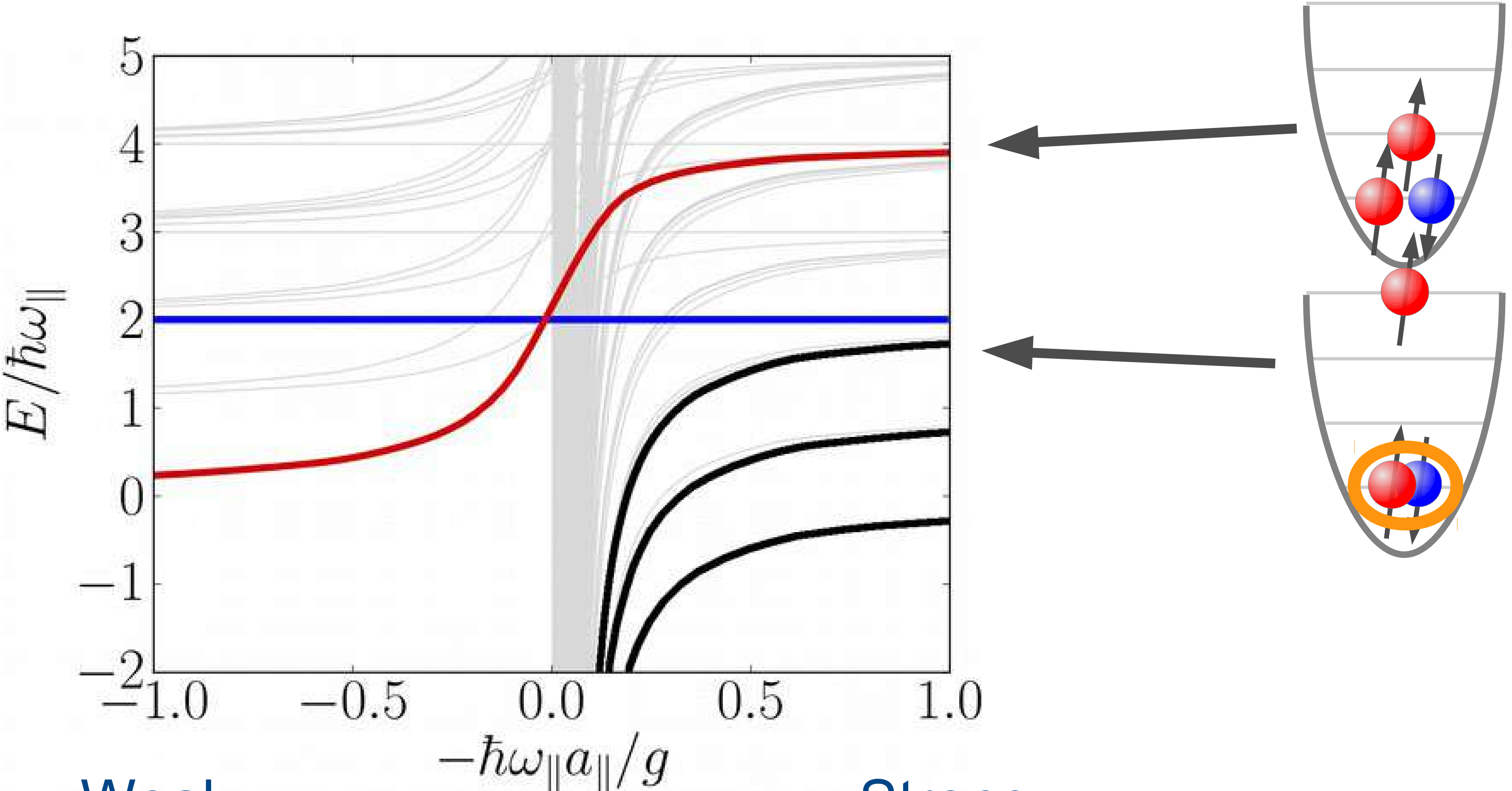


Weak

Strong



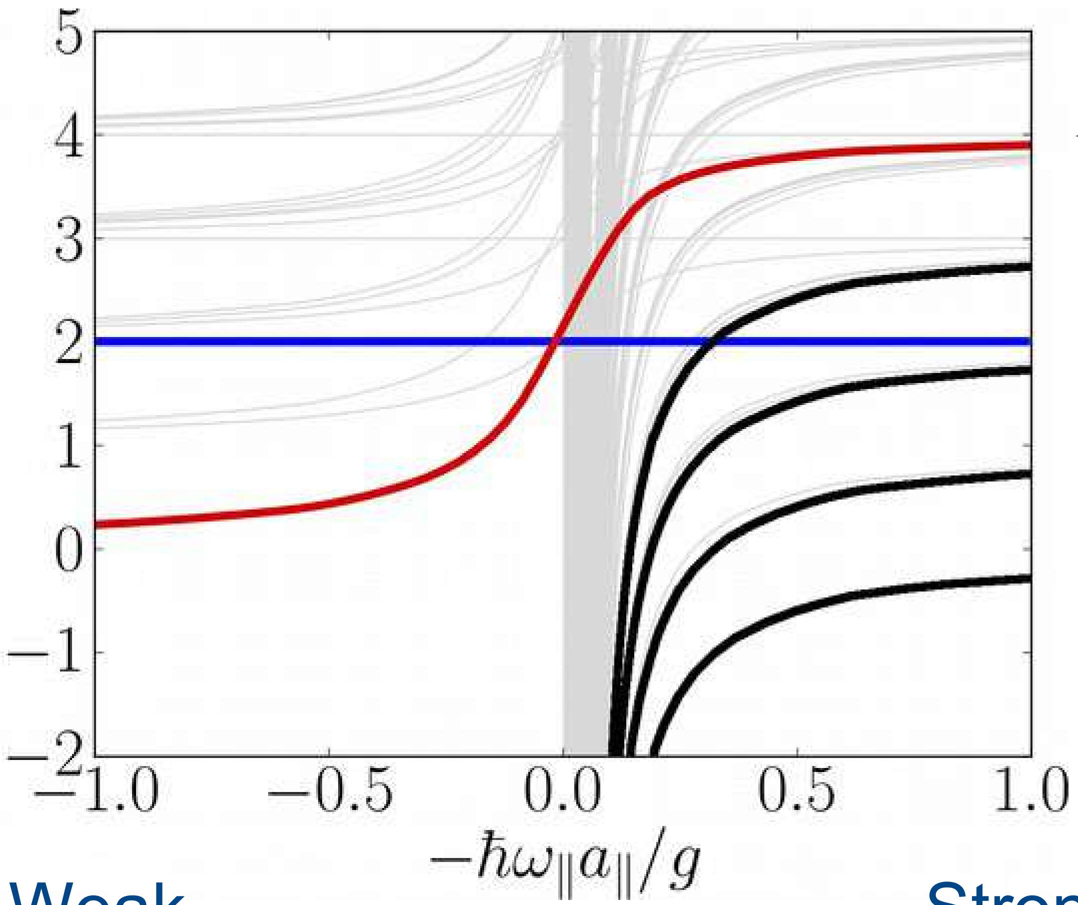
Three-atom bound state

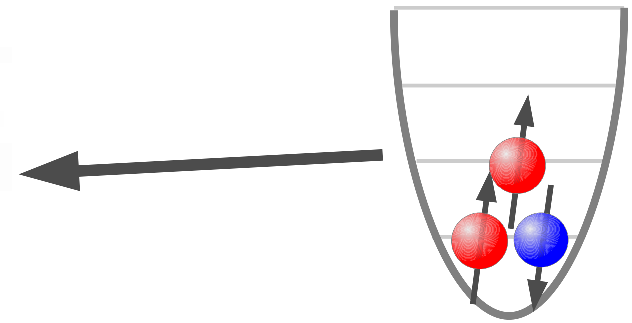


Weak

Strong

Three-atom bound state

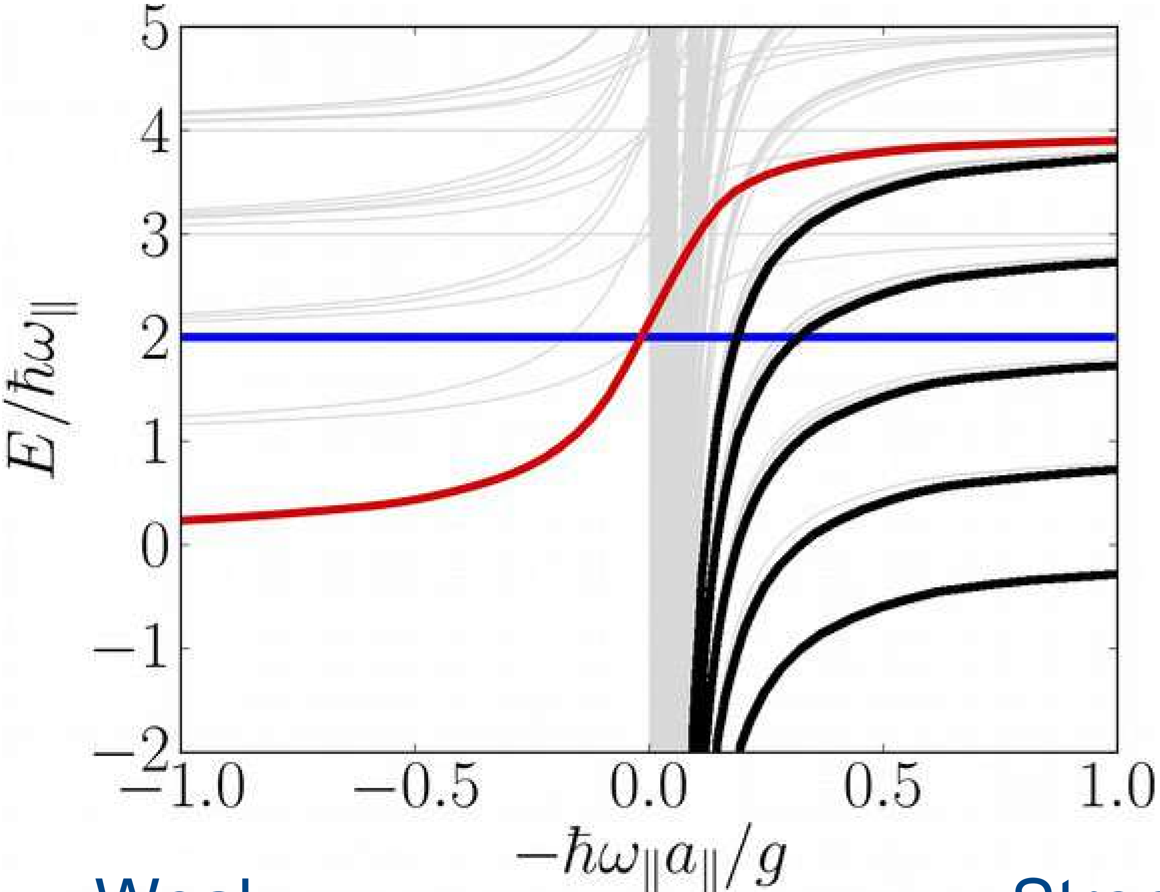


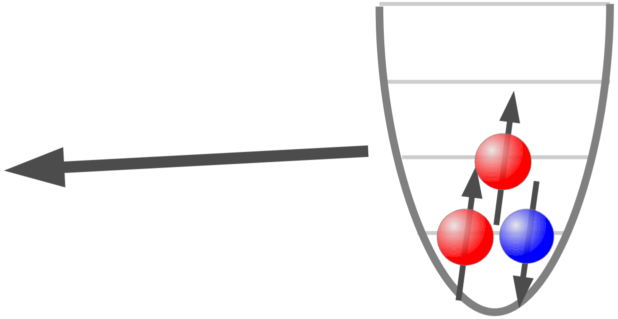


Weak

Strong

Three-atom bound state

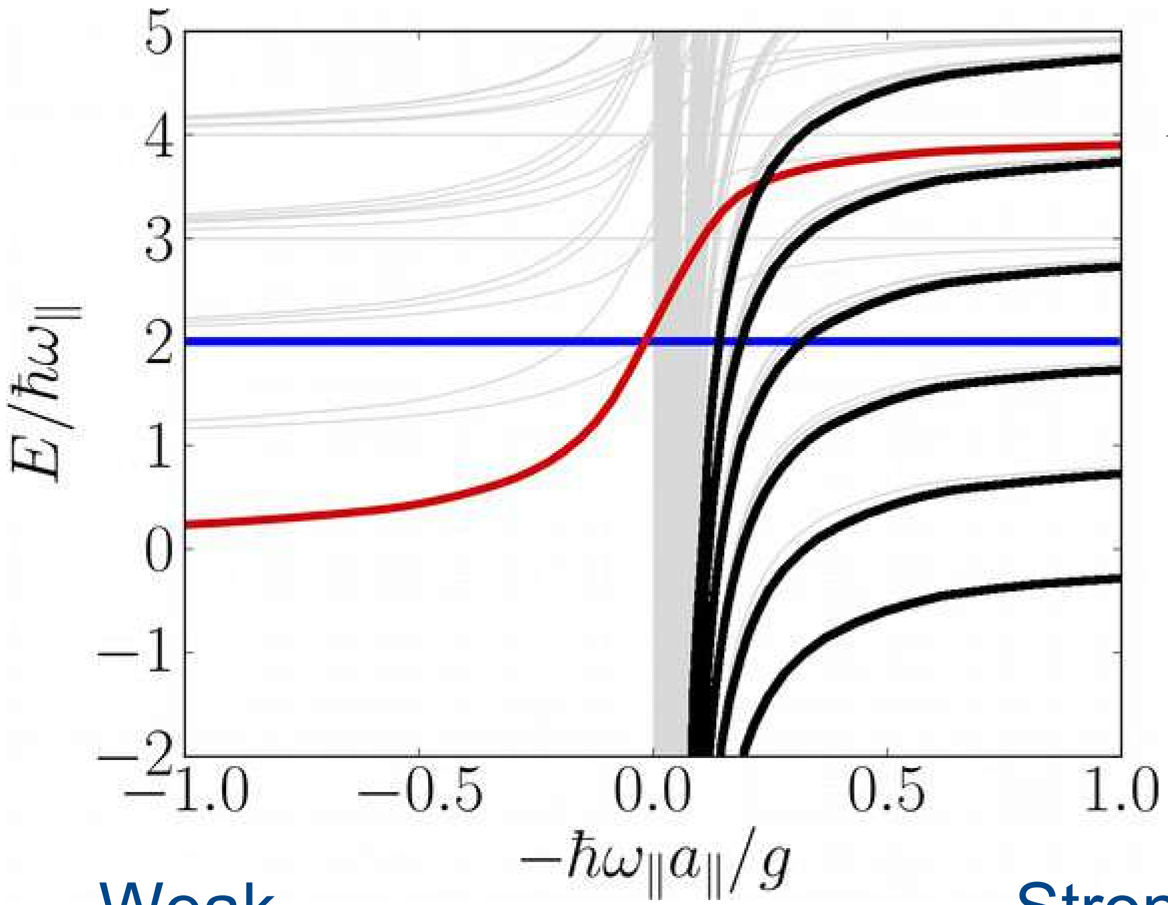


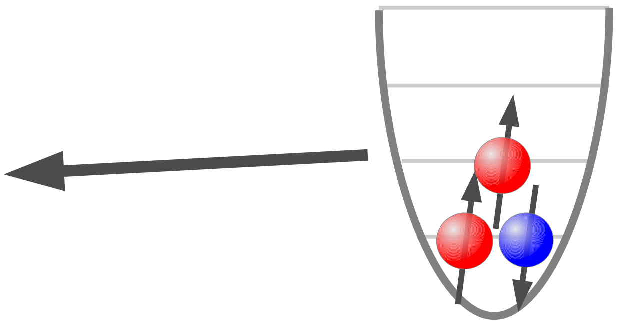


Weak

Strong

Three-atom bound state

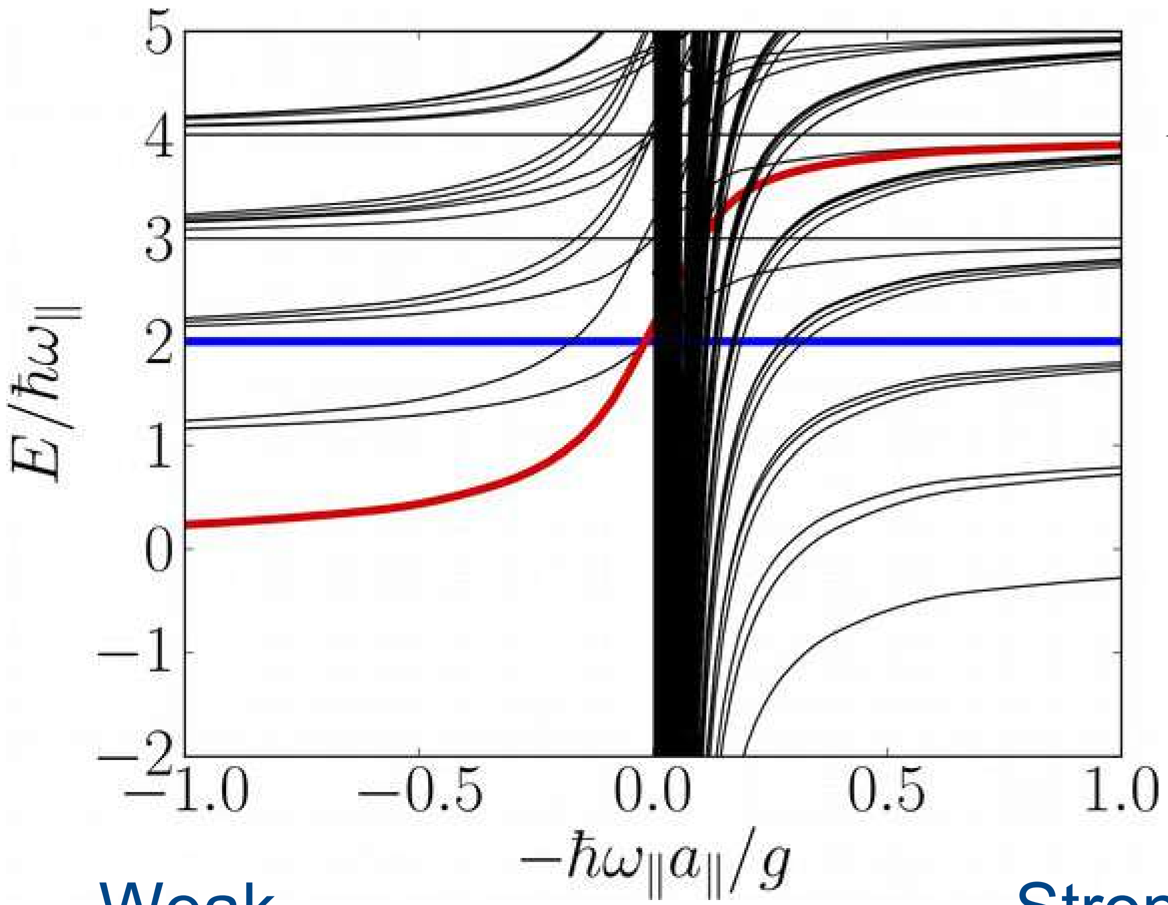


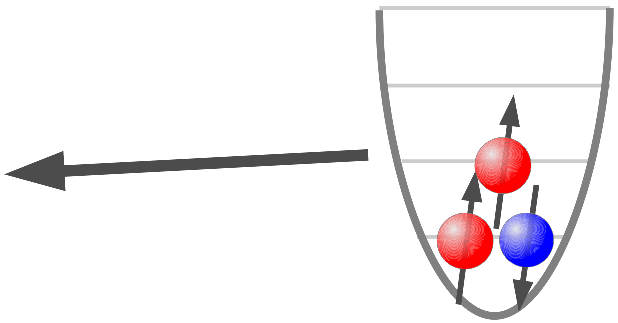


Weak

Strong

Three-atom bound state

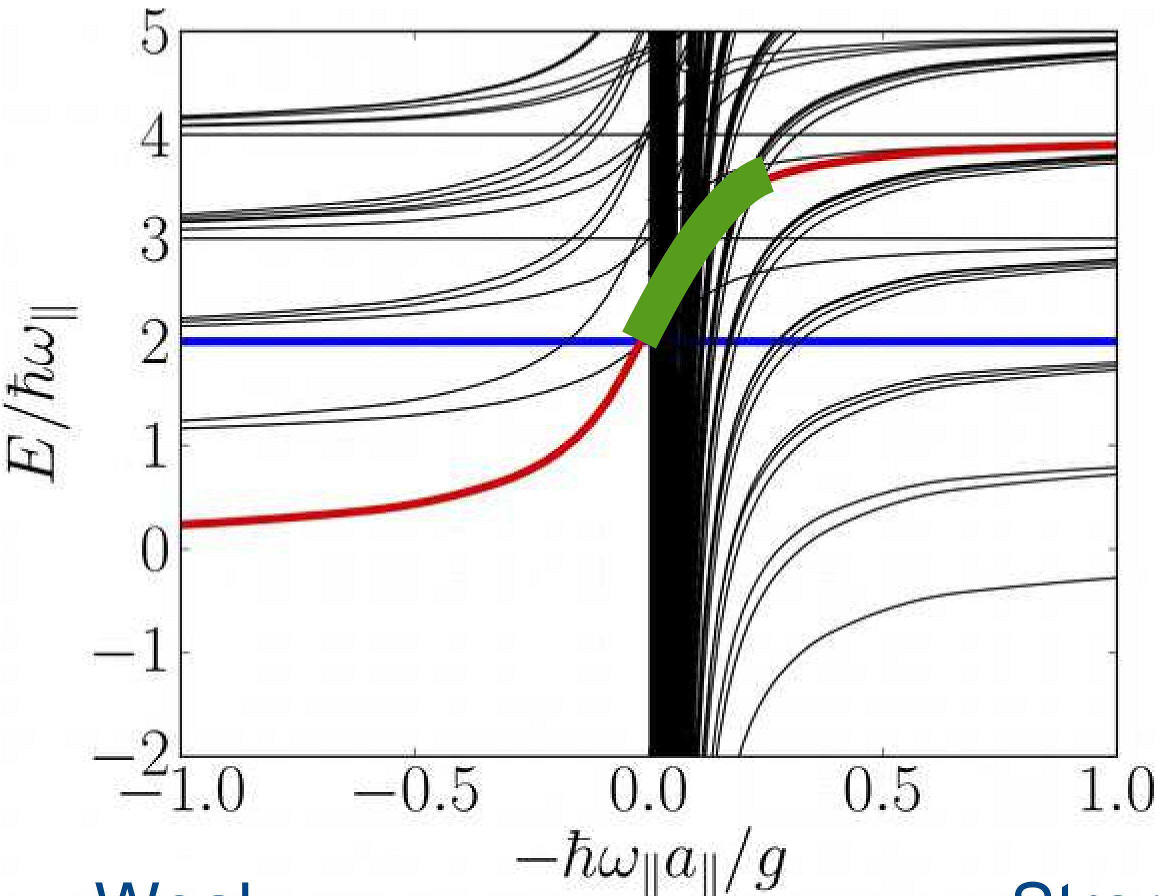




Weak

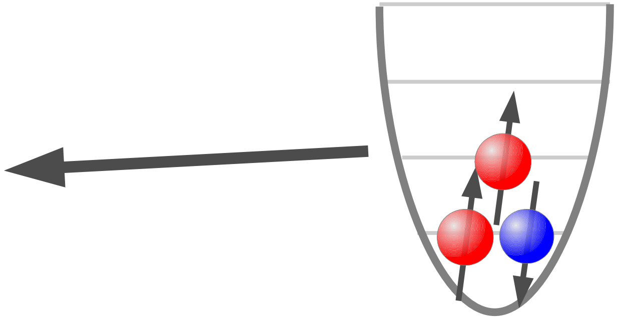
Strong

Three-atom bound state

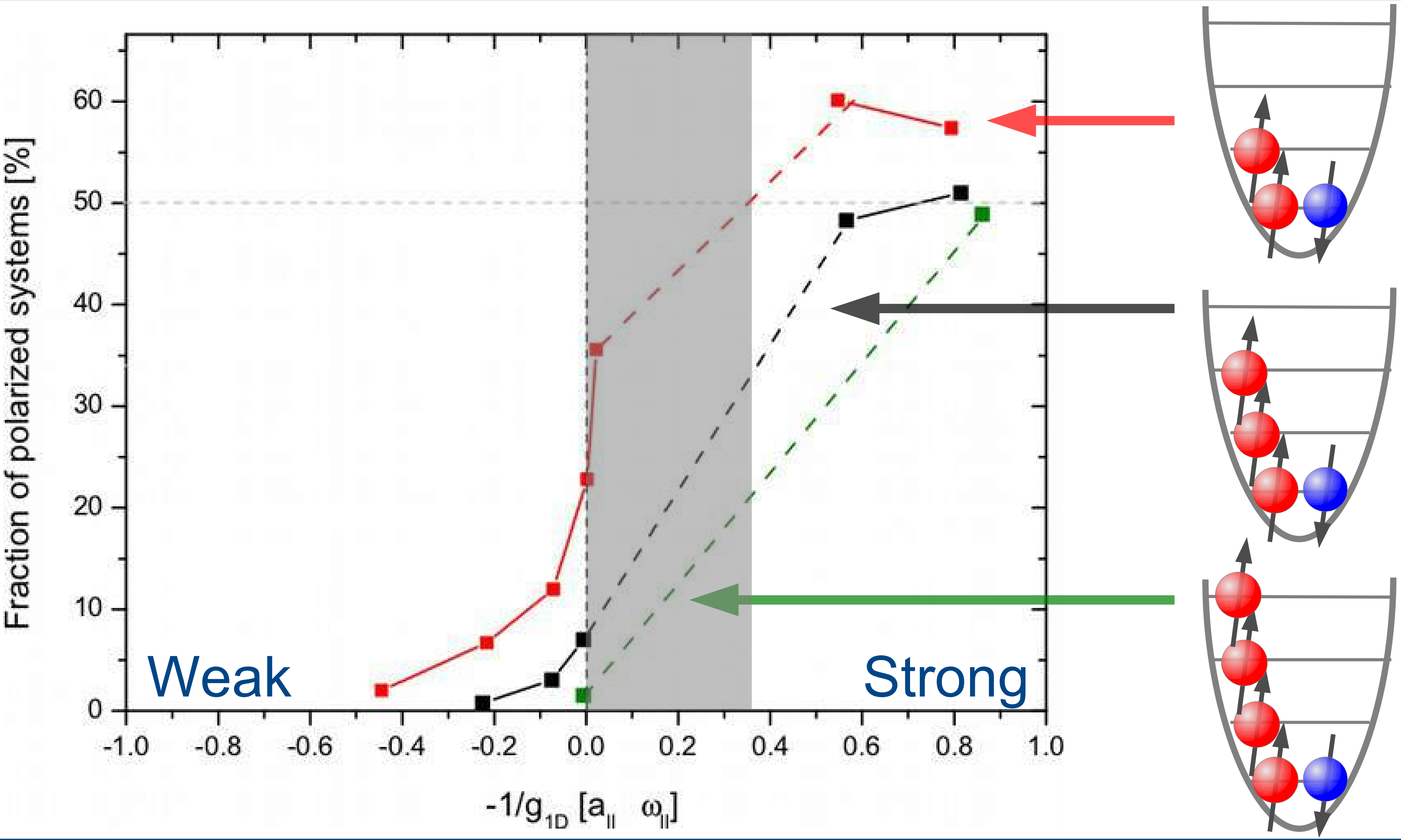


Weak

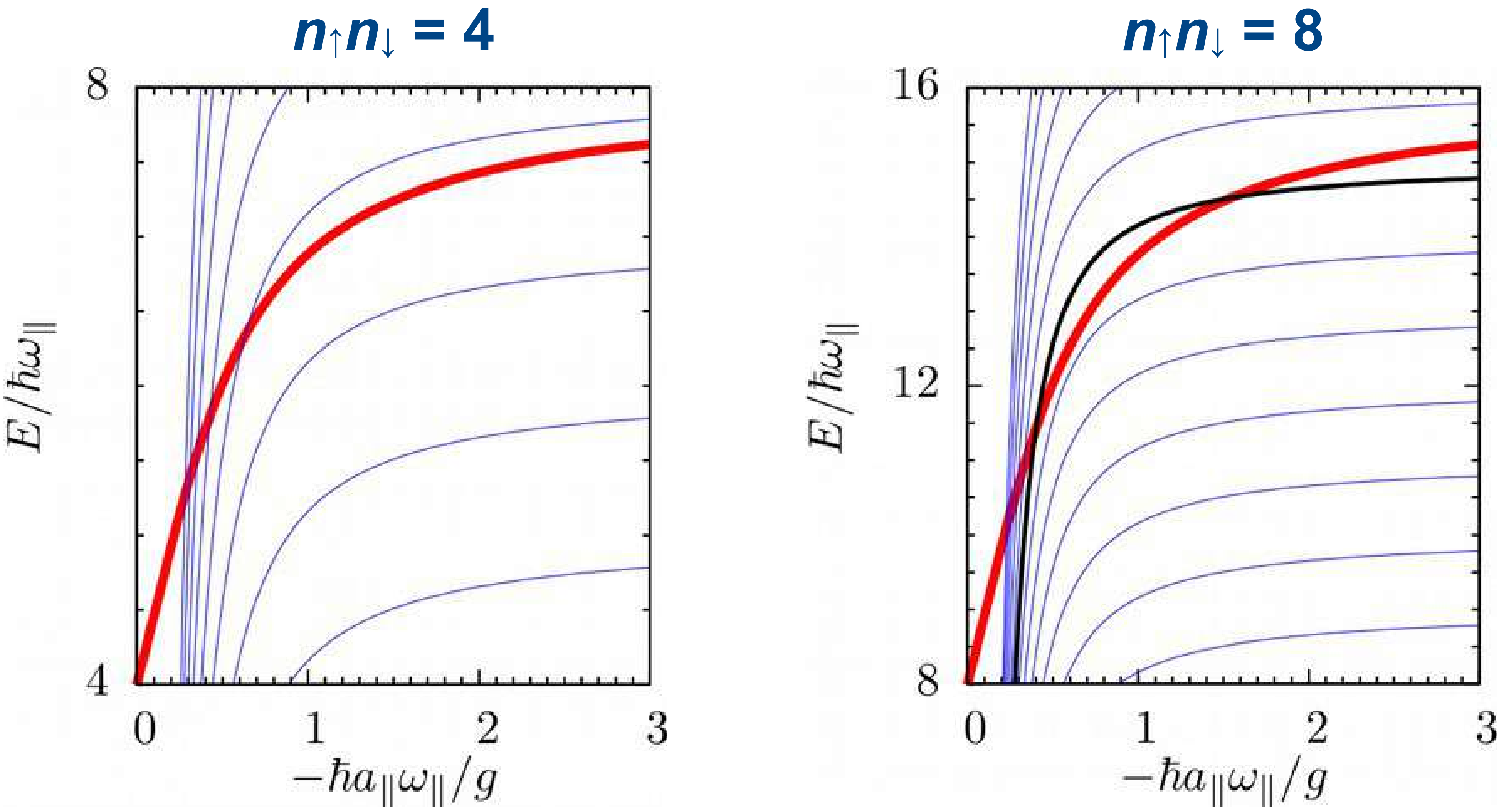
Strong



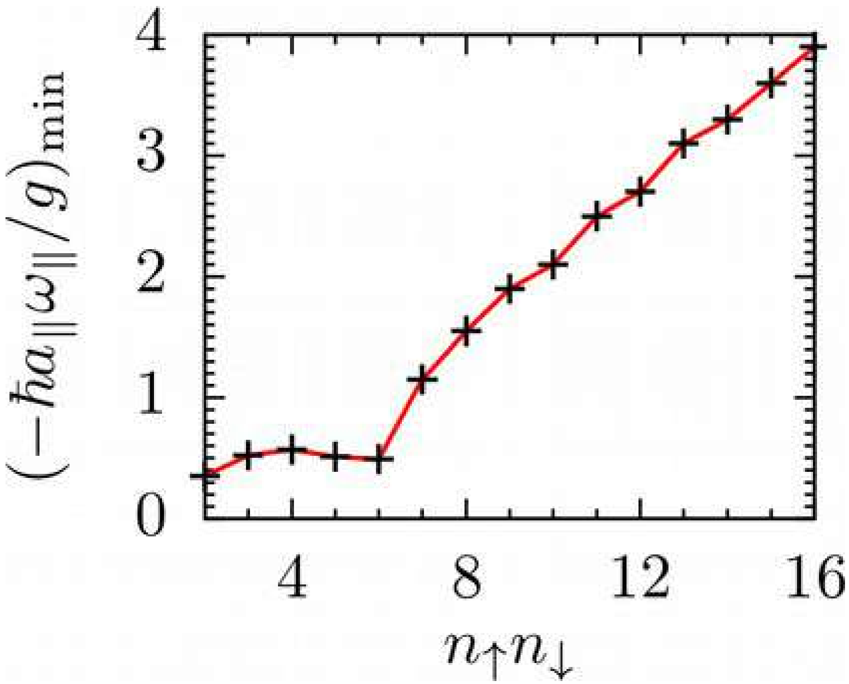
Tunneling probability



Band crossings



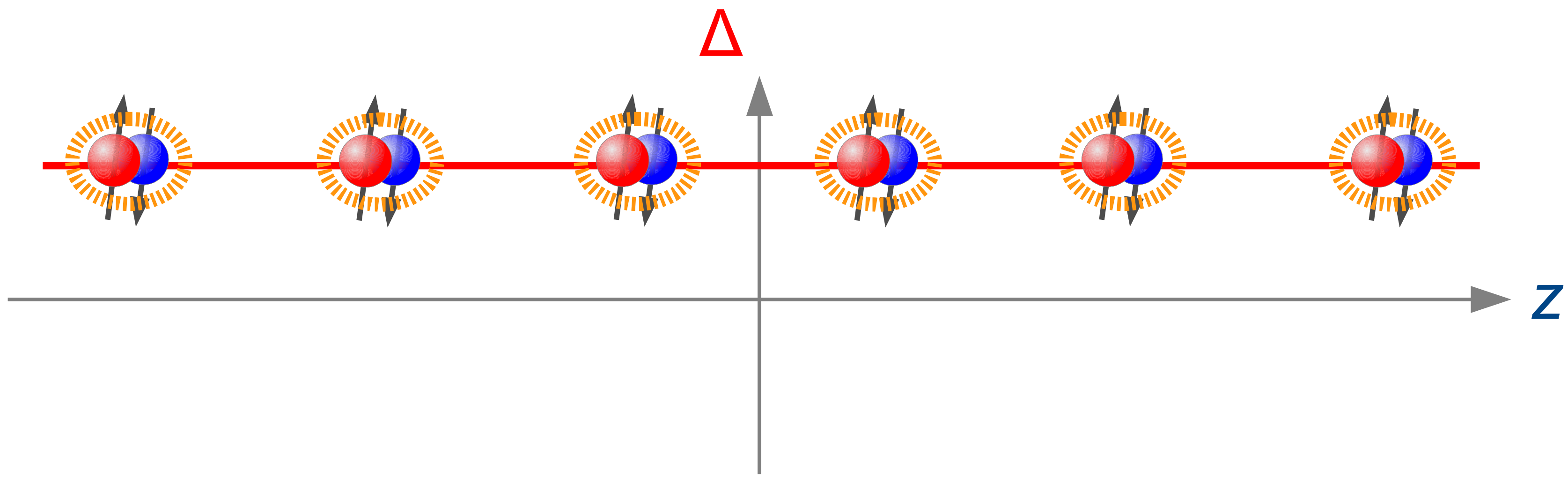
Band crossings



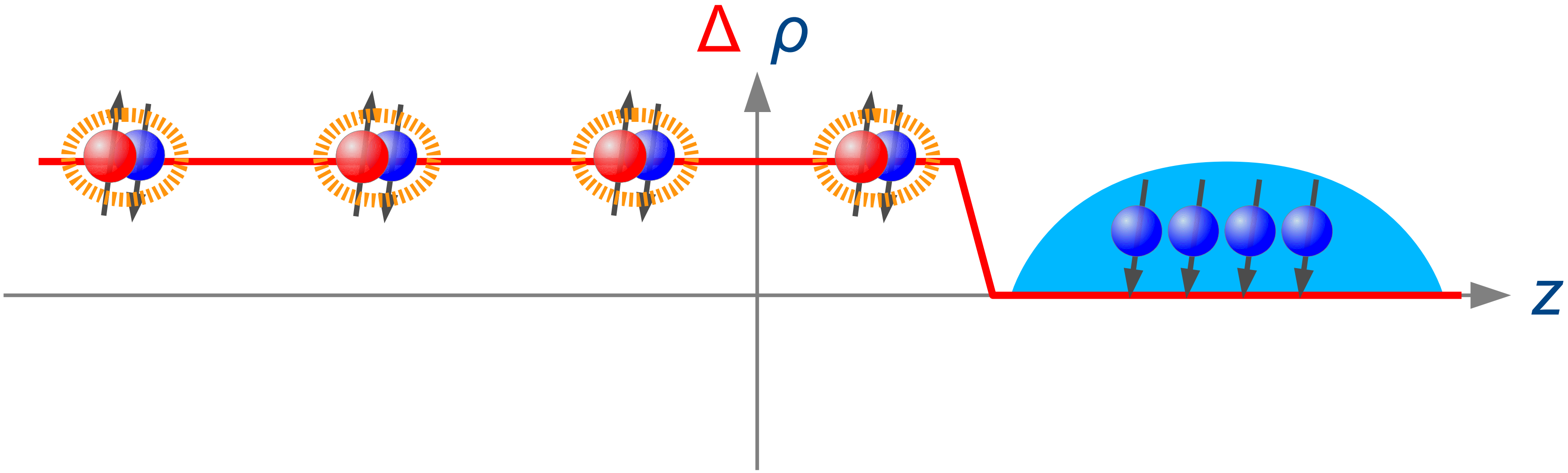
BCS Hamiltonian

$$\hat{H} = -\frac{\nabla^2}{2} + g c^\dagger_{\vec{p}\uparrow} c^\dagger_{-\vec{p}\downarrow} c_{-\vec{k}\downarrow} c_{\vec{k}\uparrow} + V(\vec{r})$$

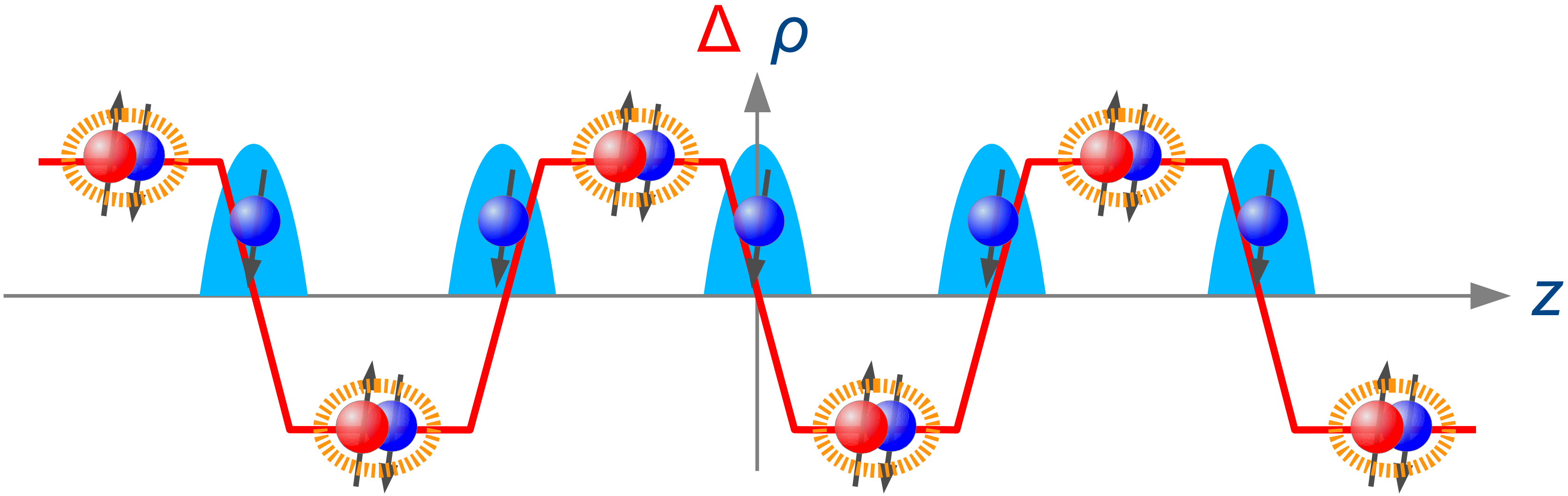
Inhomogeneous pairing



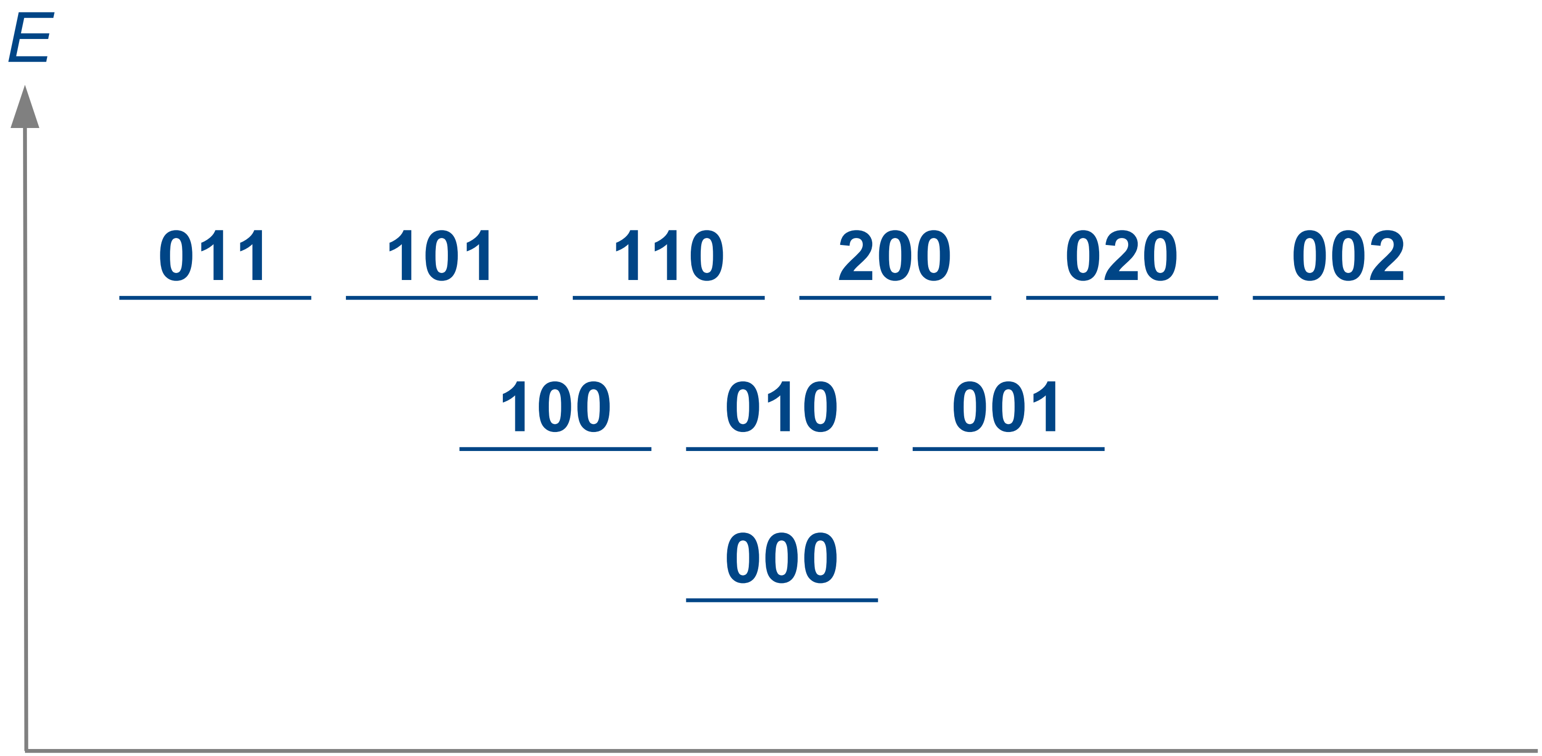
Inhomogeneous pairing



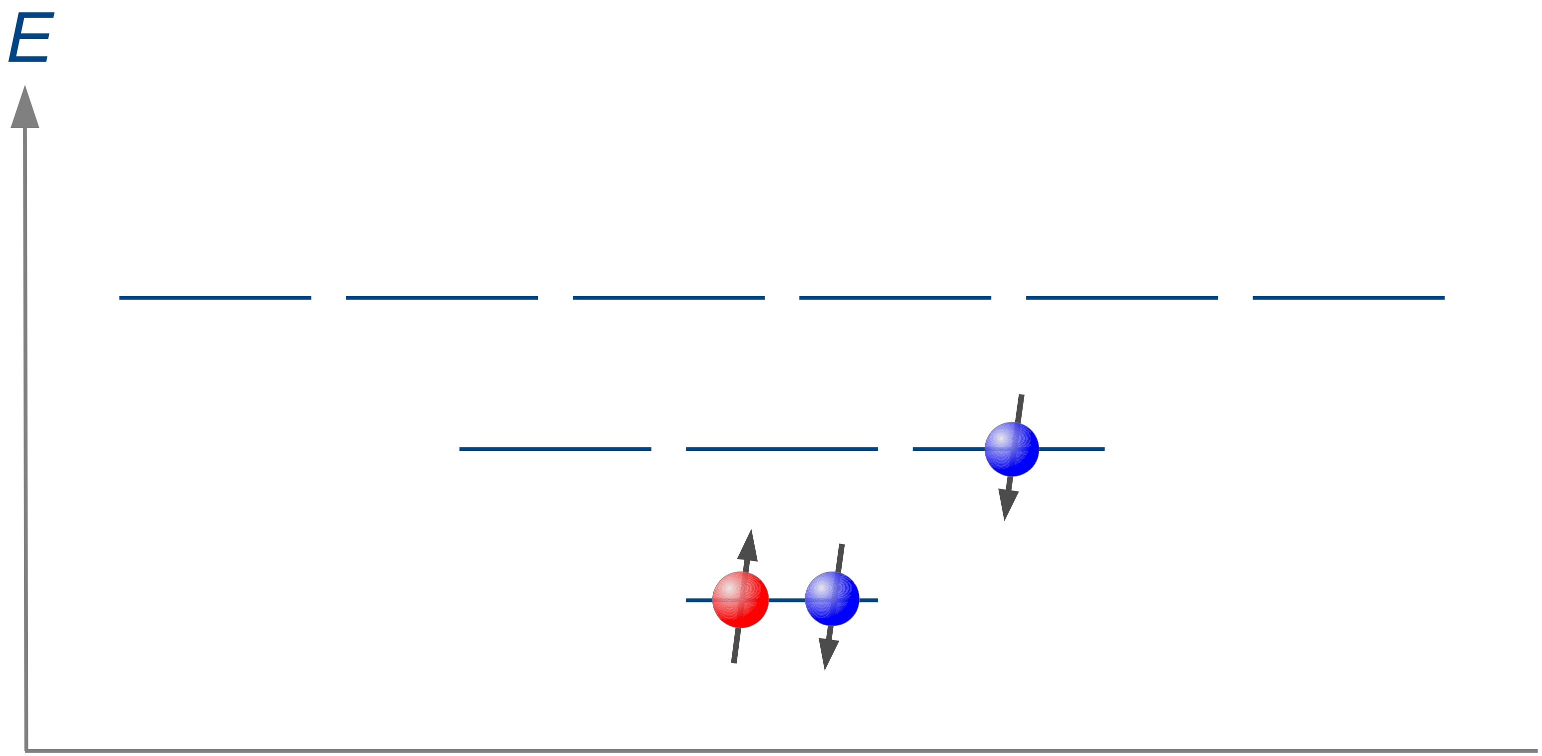
Inhomogeneous pairing



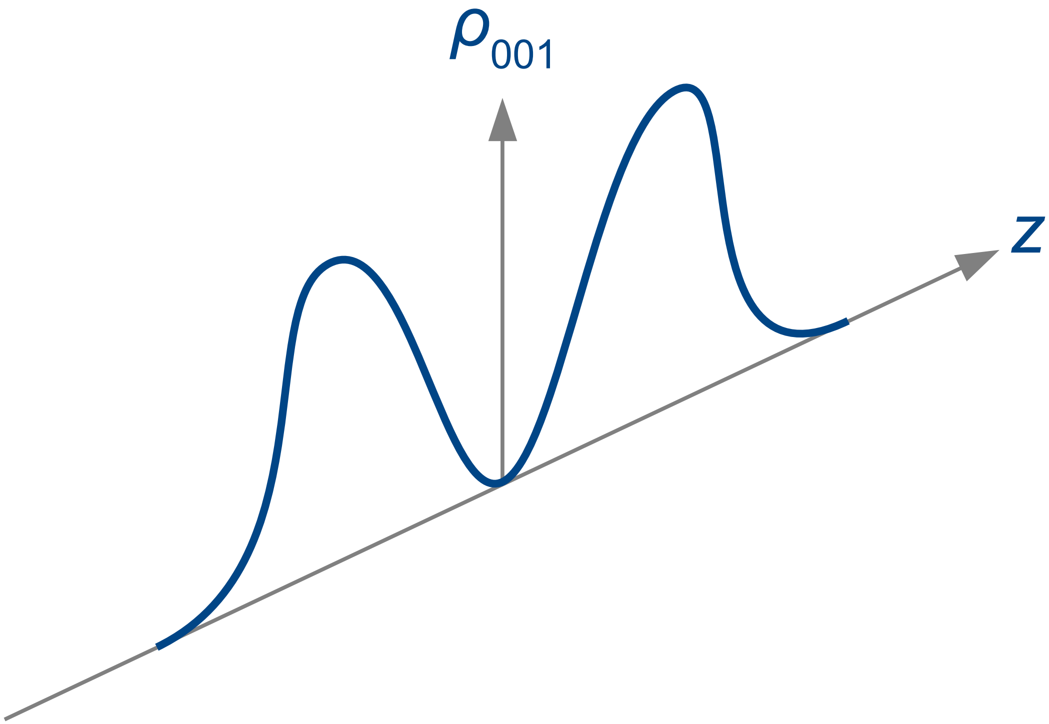
Inhomogeneous pairing



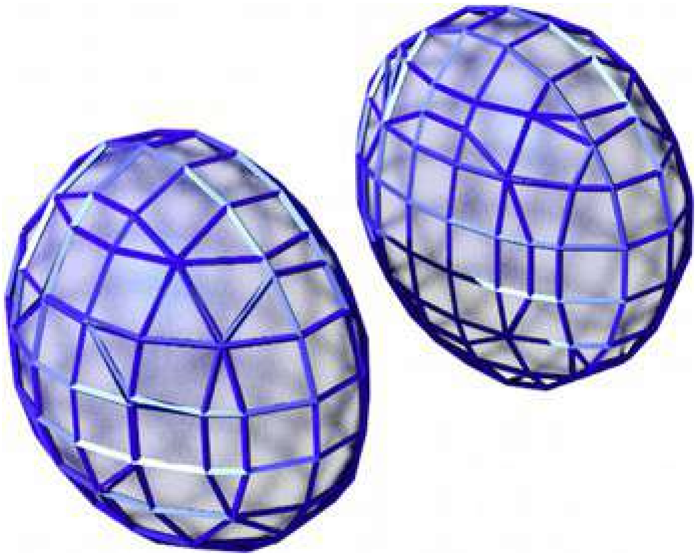
Inhomogeneous pairing



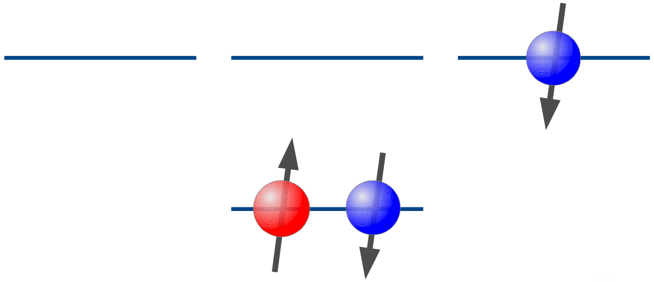
Inhomogeneous pairing

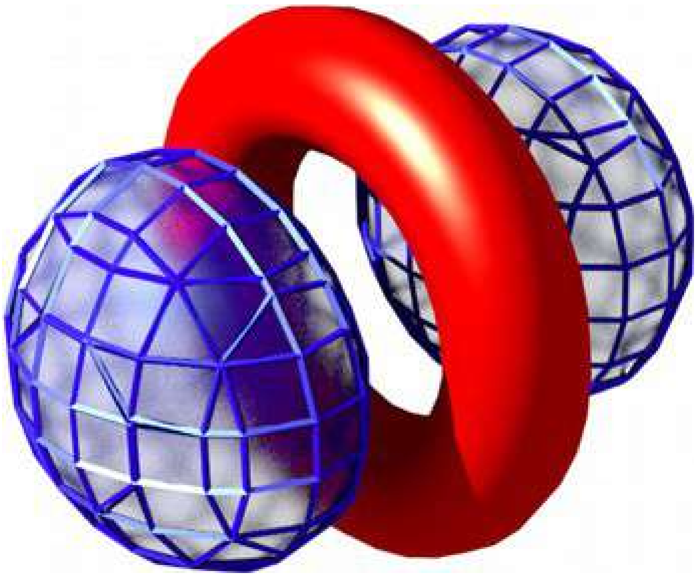


Inhomogeneous pairing

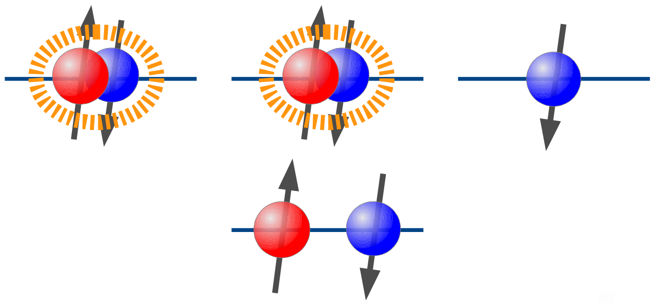


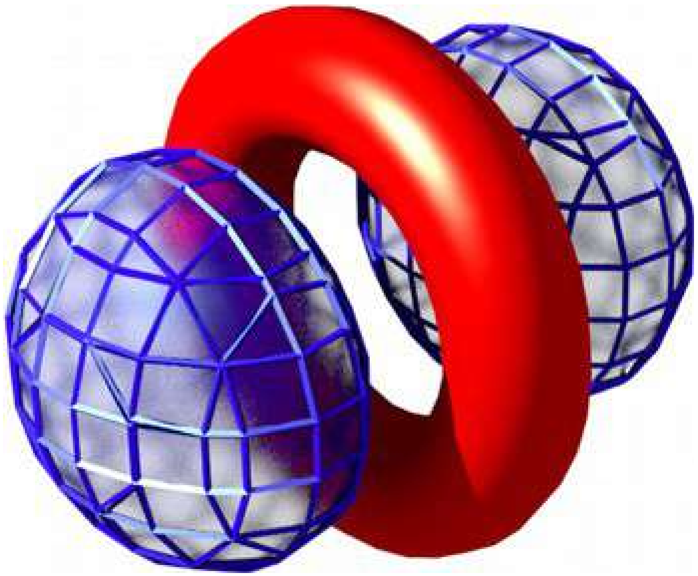
Inhomogeneous pairing



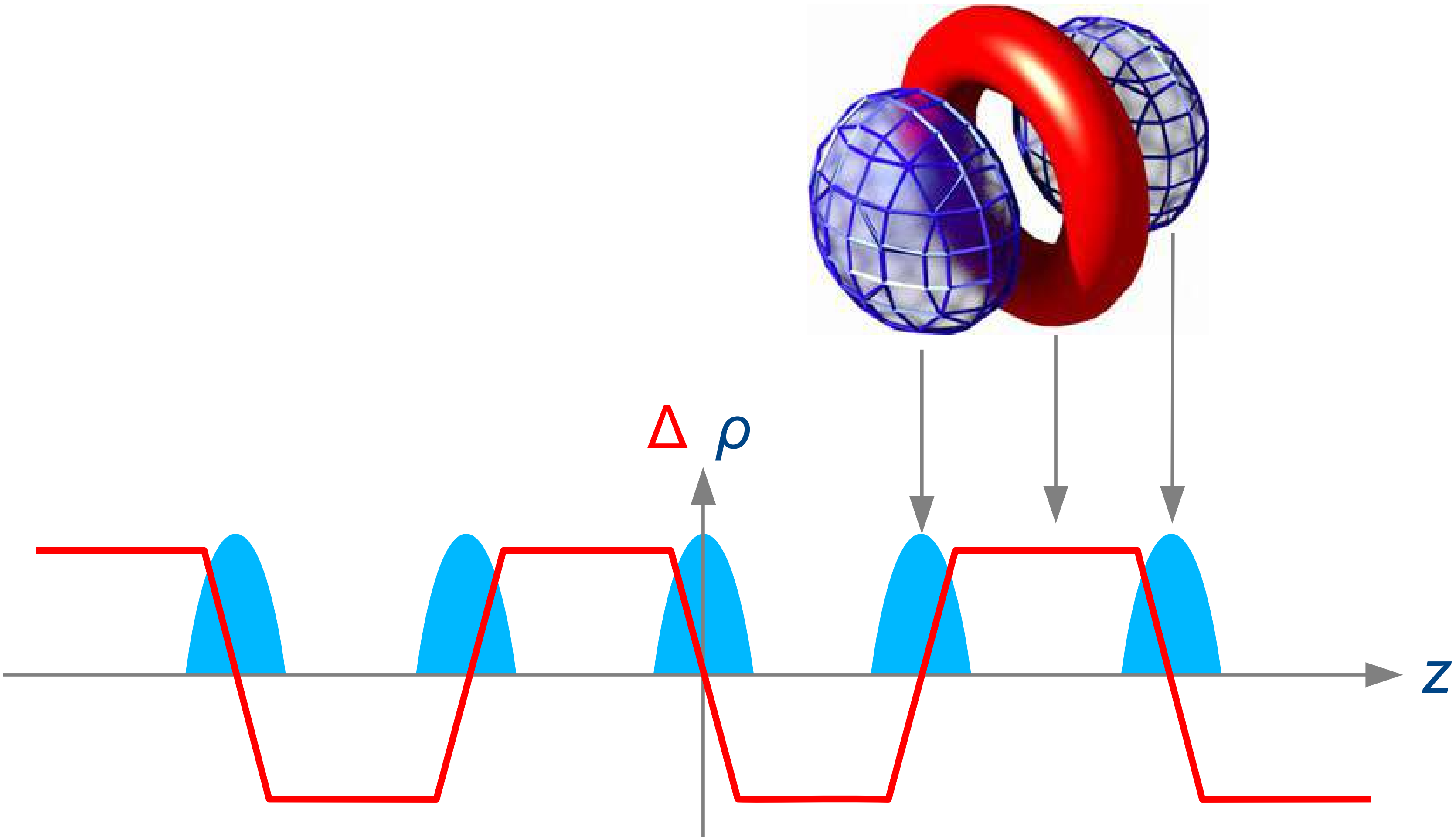


Inhomogeneous pairing



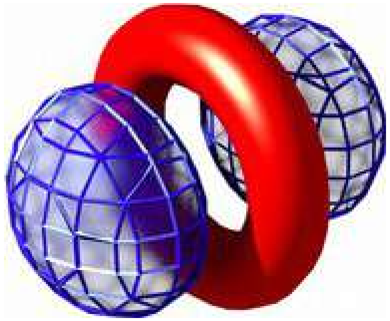


Inhomogeneous pairing

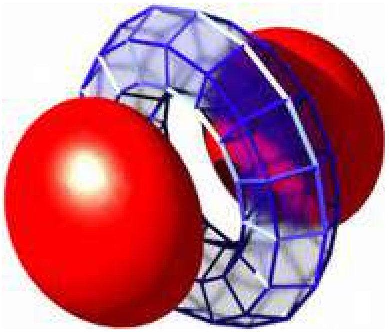


Inhomogeneous pairing

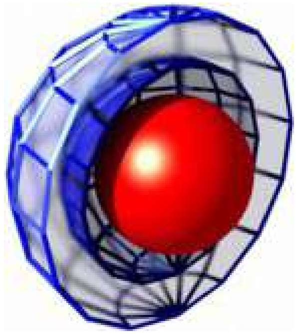
(2,1) (3,2) (4,3)



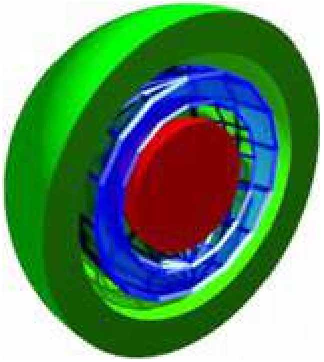
(3,1) (4,2)



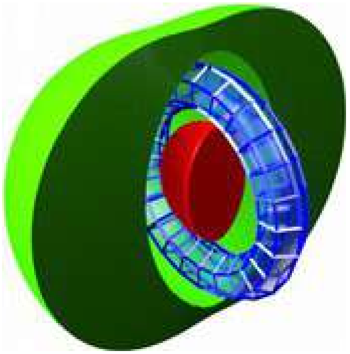
(4,1)



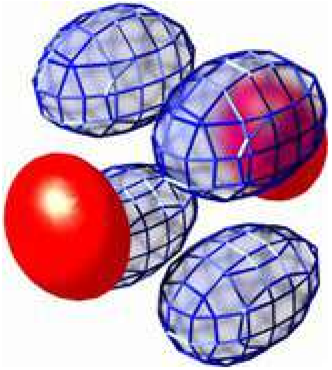
$(2,1)^s$ (5,1)



$(2,1)^d$ (5,2)

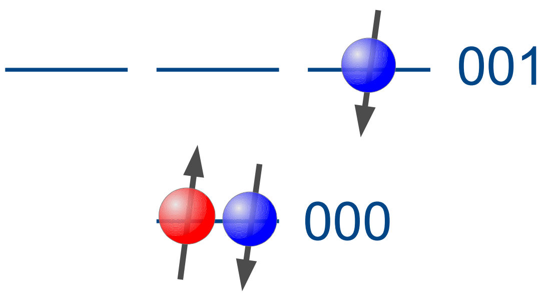


$(2,1)^g$

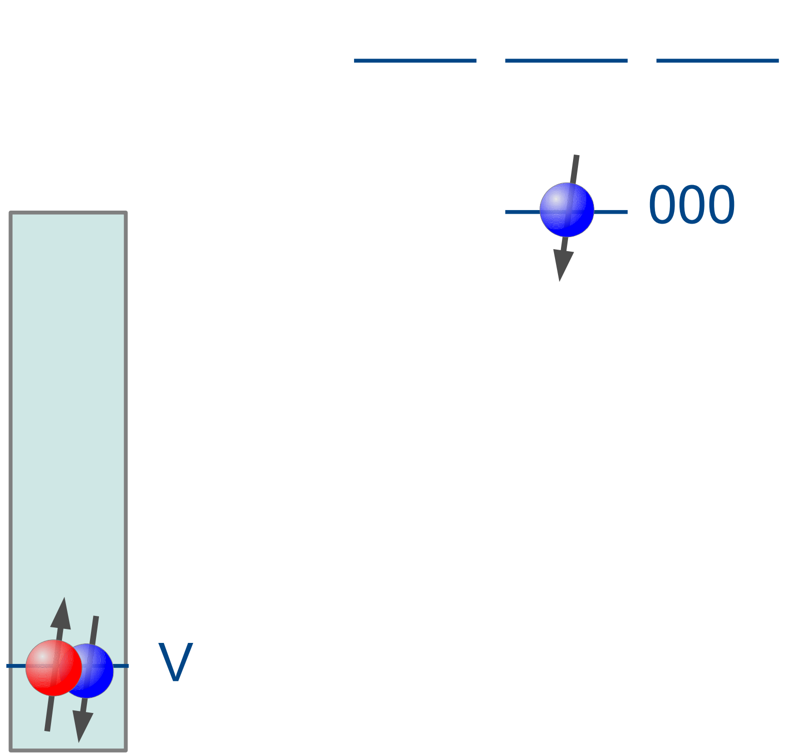


Inhomogeneous pairing

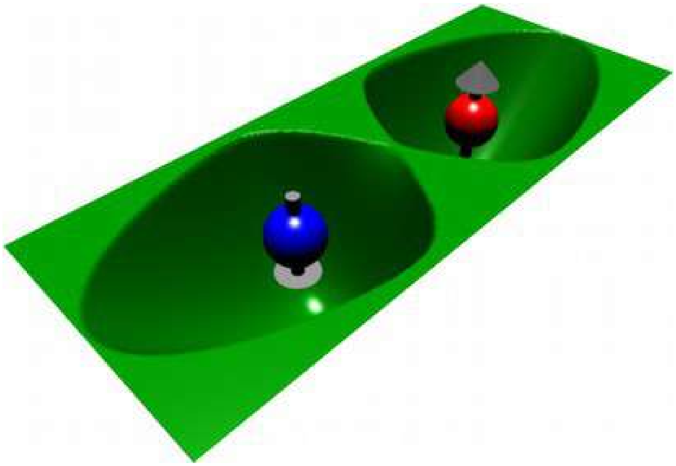
Weak interactions



Strong interactions

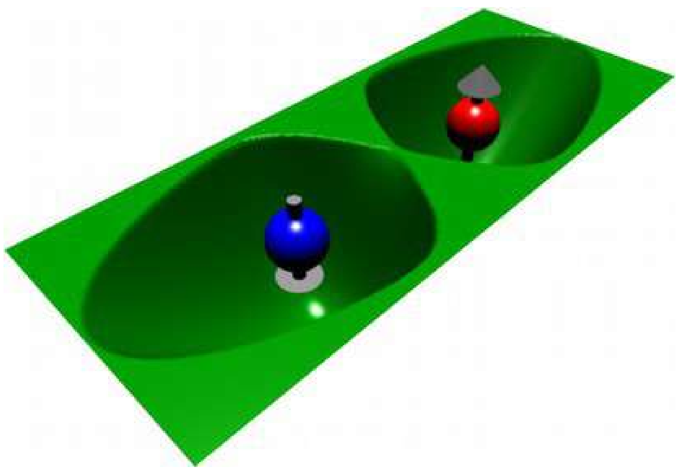


Inhomogeneous pairing



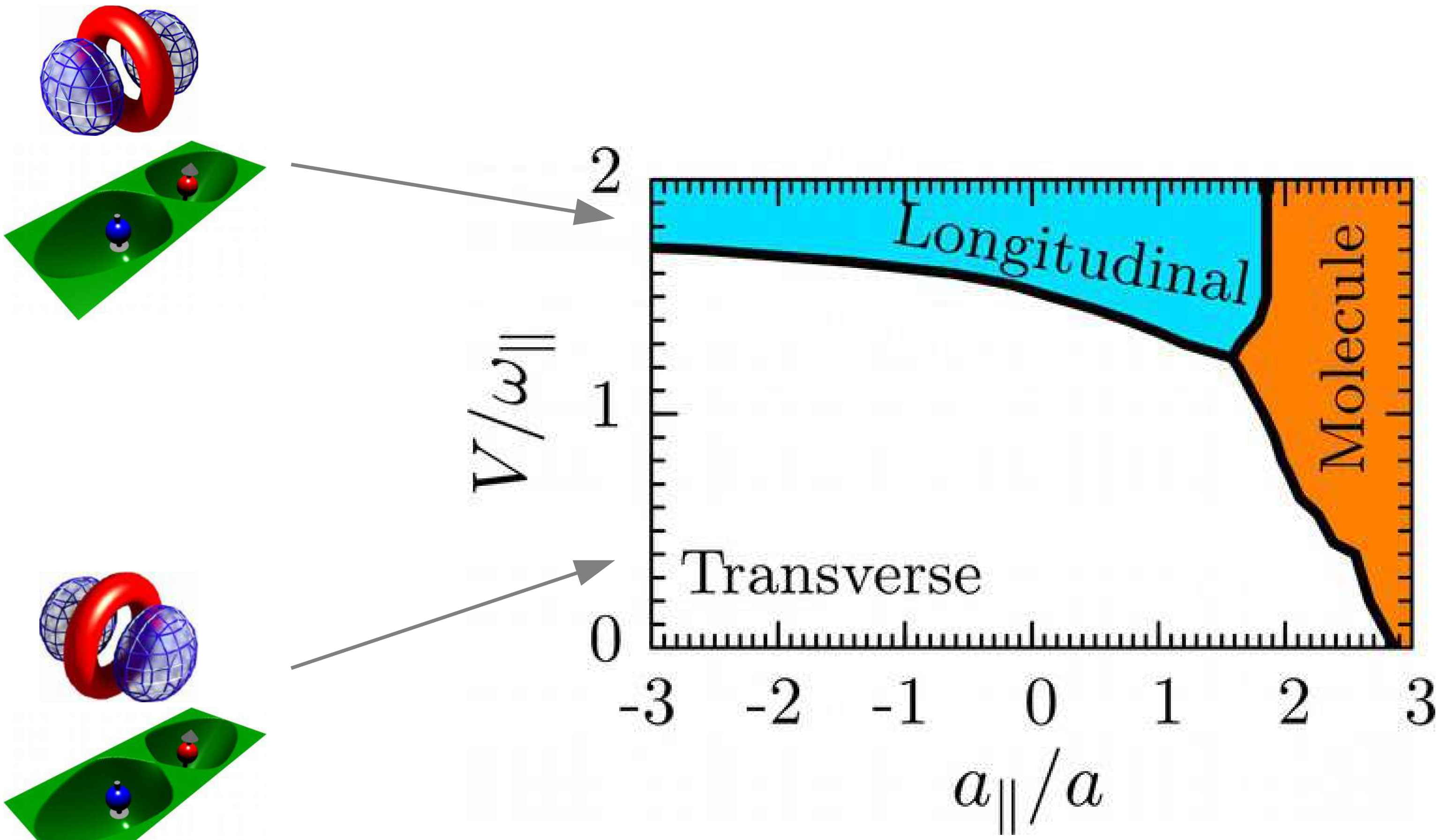
P.O. Bugnion & GJC, Phys. Rev. A **88**, 013601 (2013)

Inhomogeneous pairing



P.O. Bugnion & GJC, Phys. Rev. A **88**, 013601 (2013)

Inhomogeneous pairing



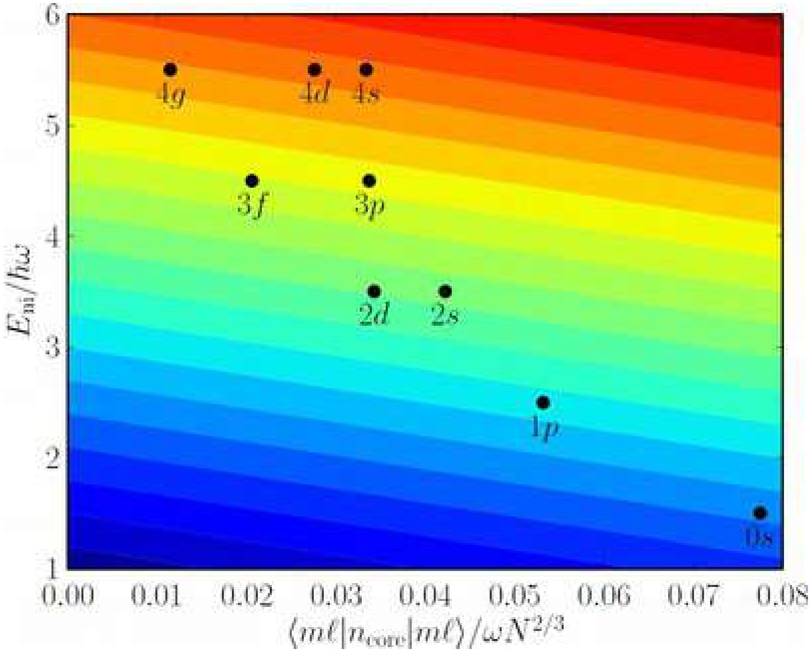
Summary

A few-fermion system provides insight into many-body physics

Discretization of energy levels means that losses occur in narrow range of interaction strengths

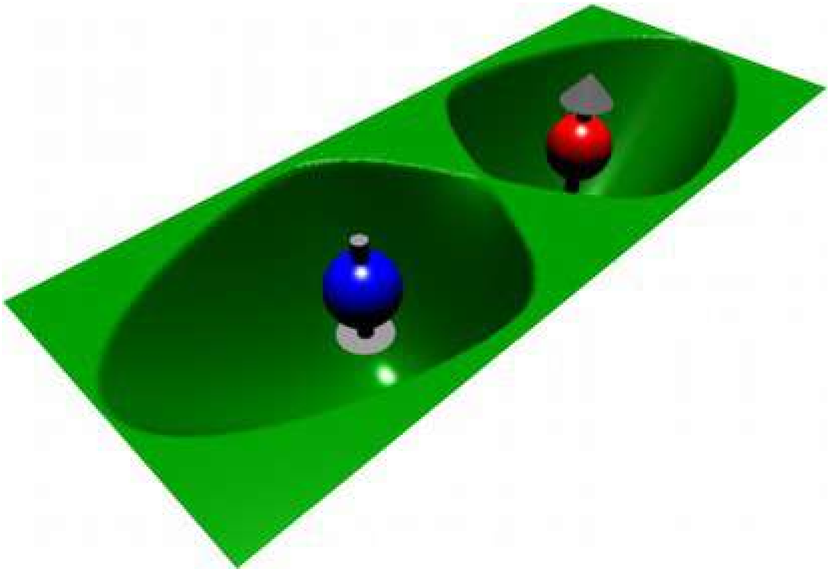
Observation of Fermi surface and magnetic correlations

Other phenomena



Hund's rules

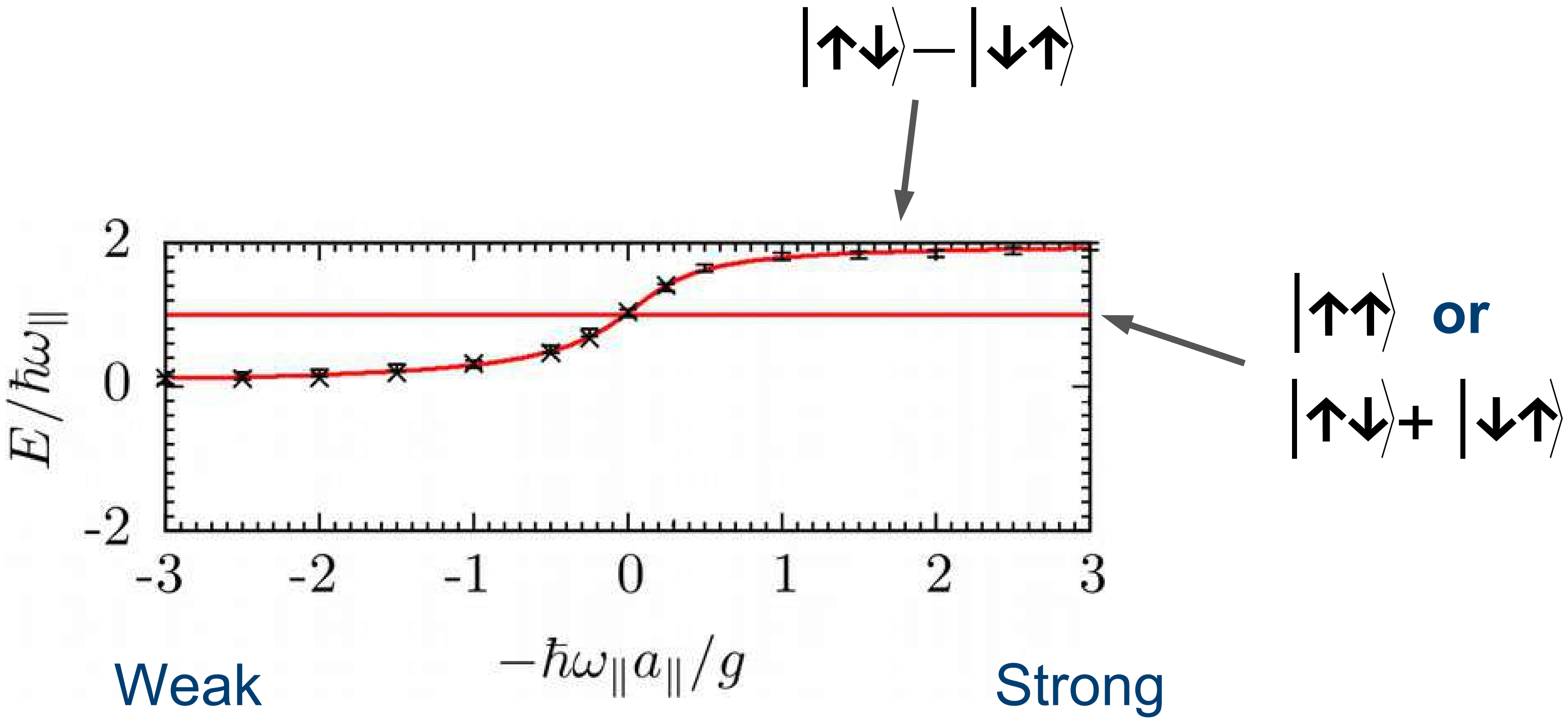
P.O. Bugnion, J.A. Lofthouse & GJC



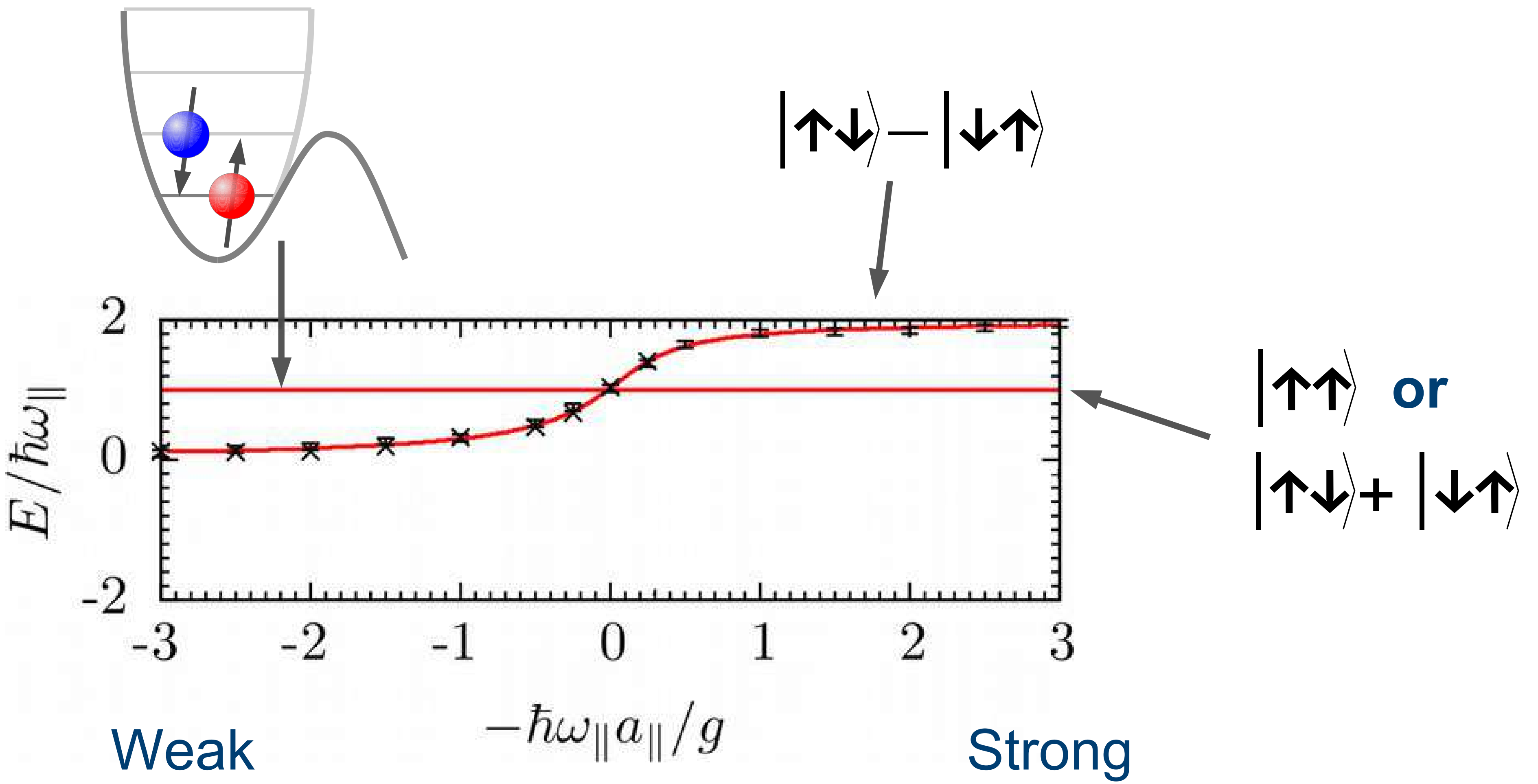
Exchange interactions

P.O. Bugnion & GJC
Phys. Rev. A **88**, 013601 (2013)

Finding the missing probability

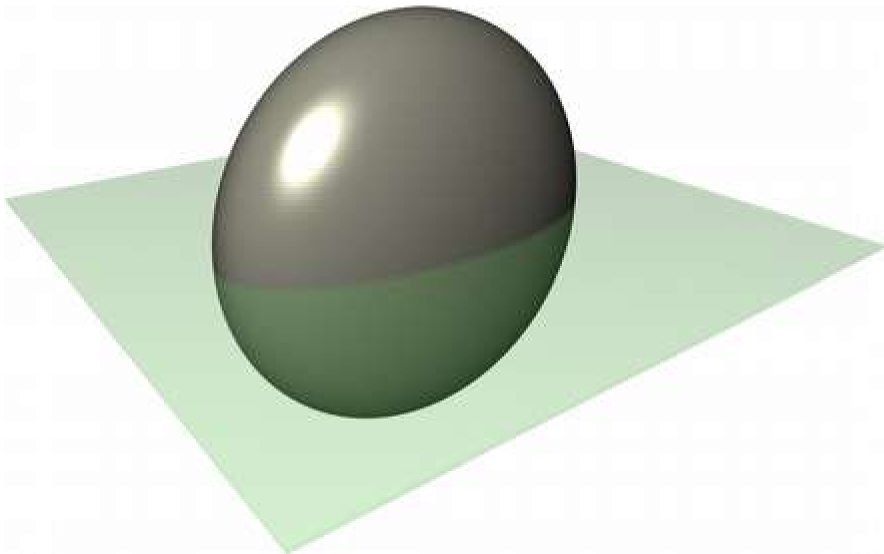


Finding the missing probability



Inhomogeneous pairing

Inhomogeneous pairing



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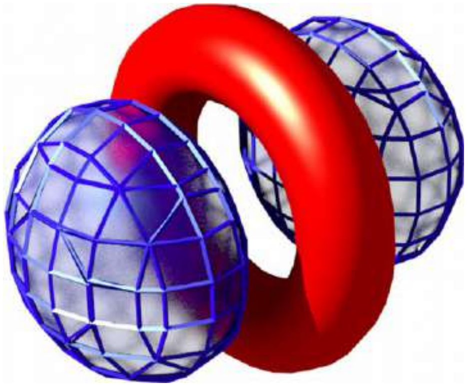

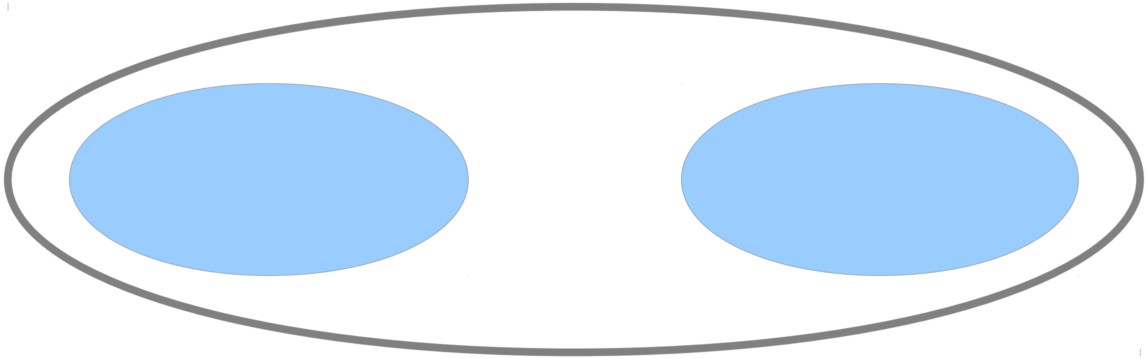

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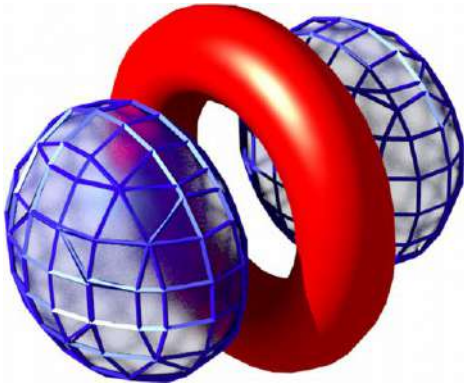

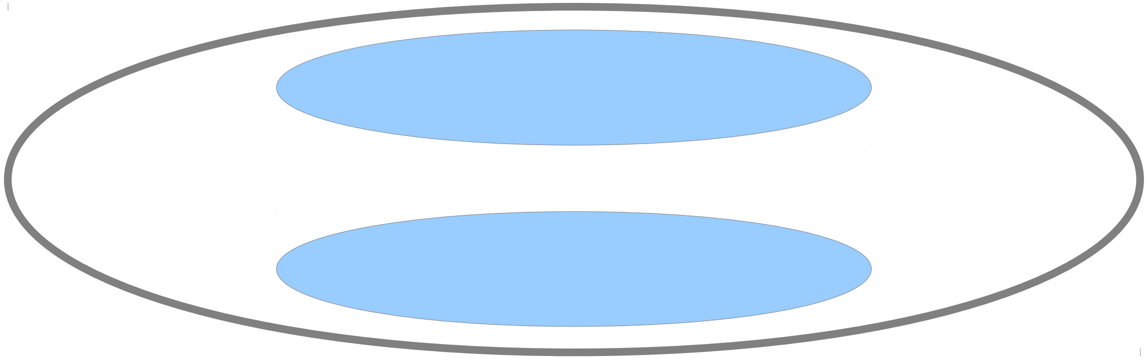

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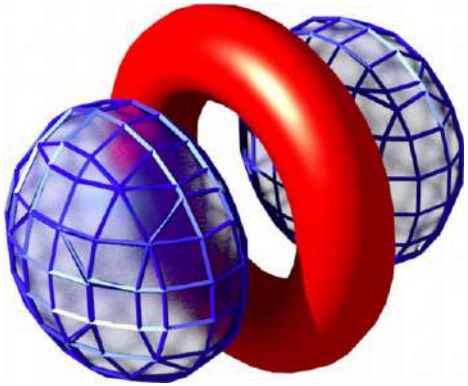

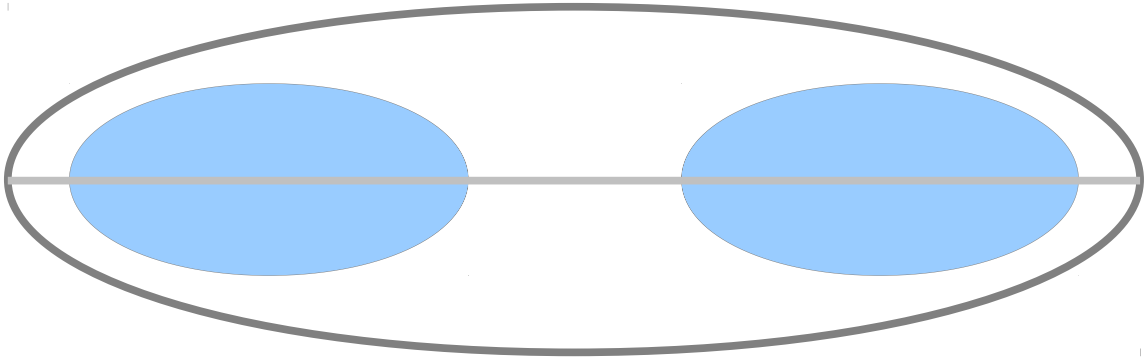

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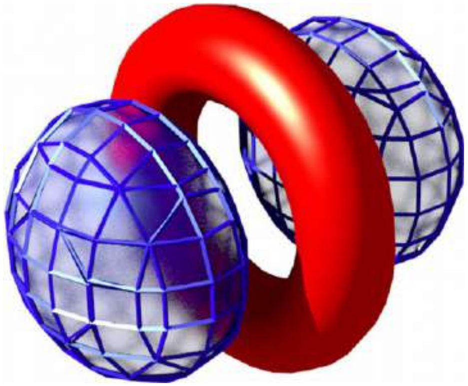

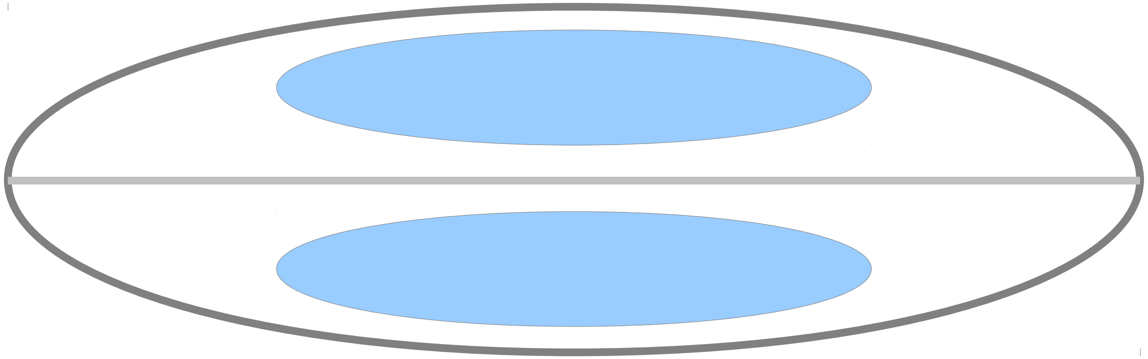

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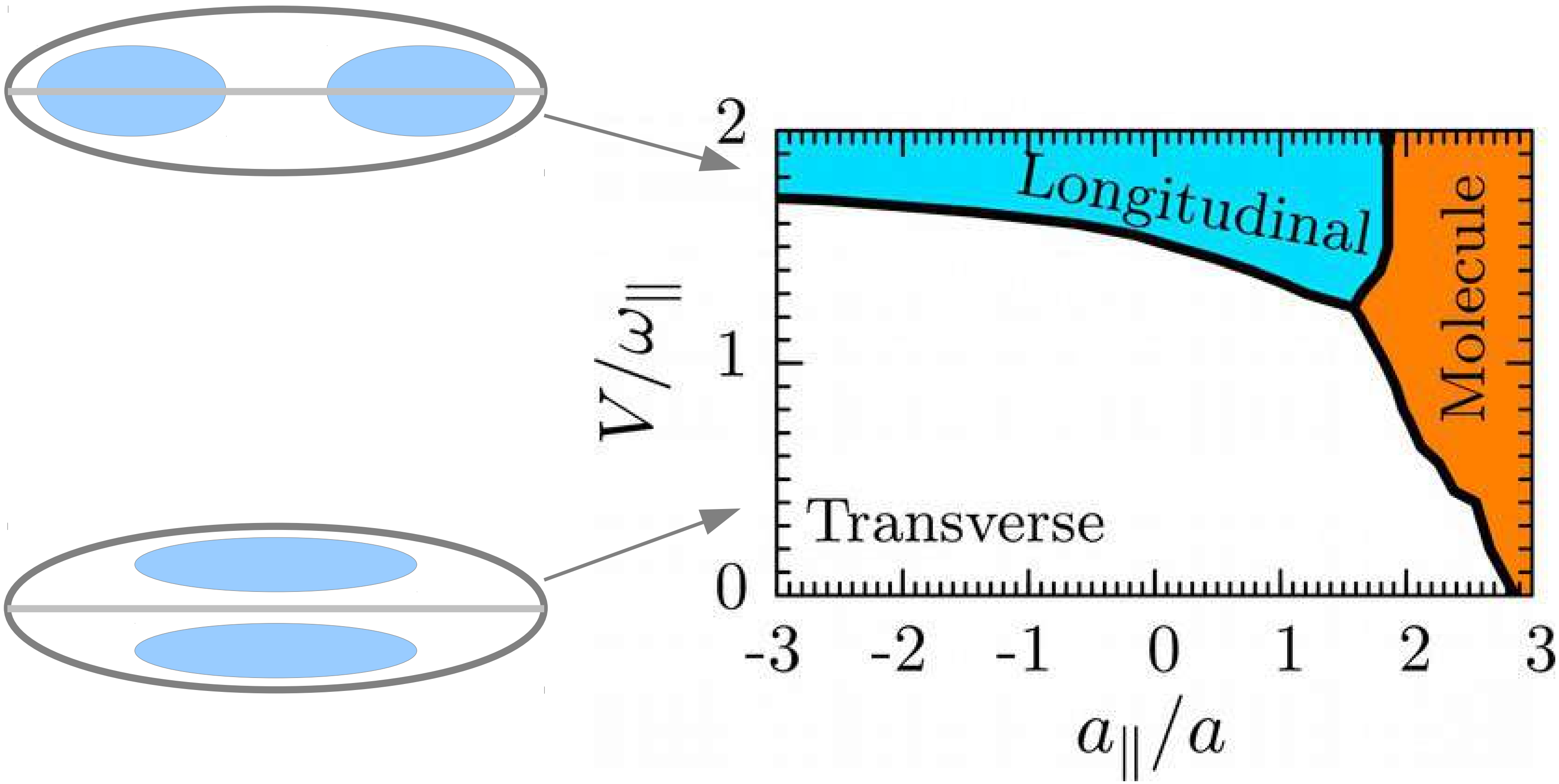
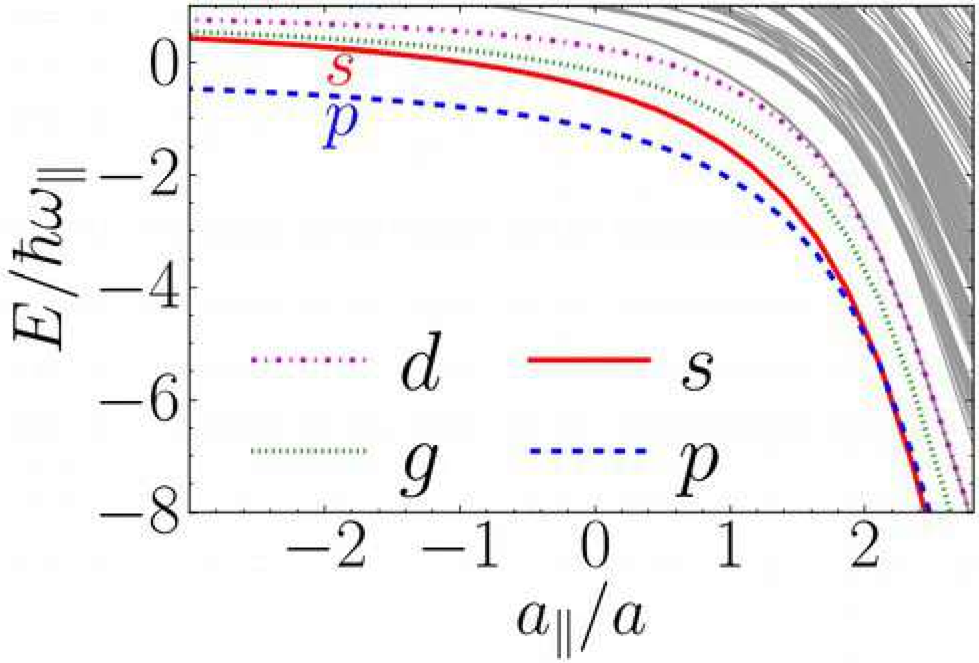


Inhomogeneous pairing



Inhomogeneous pairing