

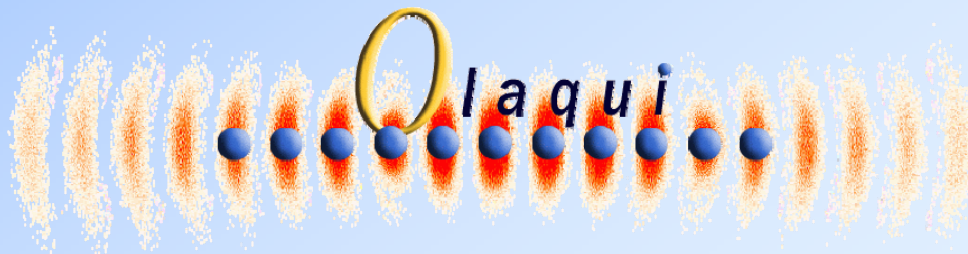
Resonantly enhanced tunnelling in optical lattices

'Quantum Mechanics', Bertinoro, 3-8 Dec. 2006

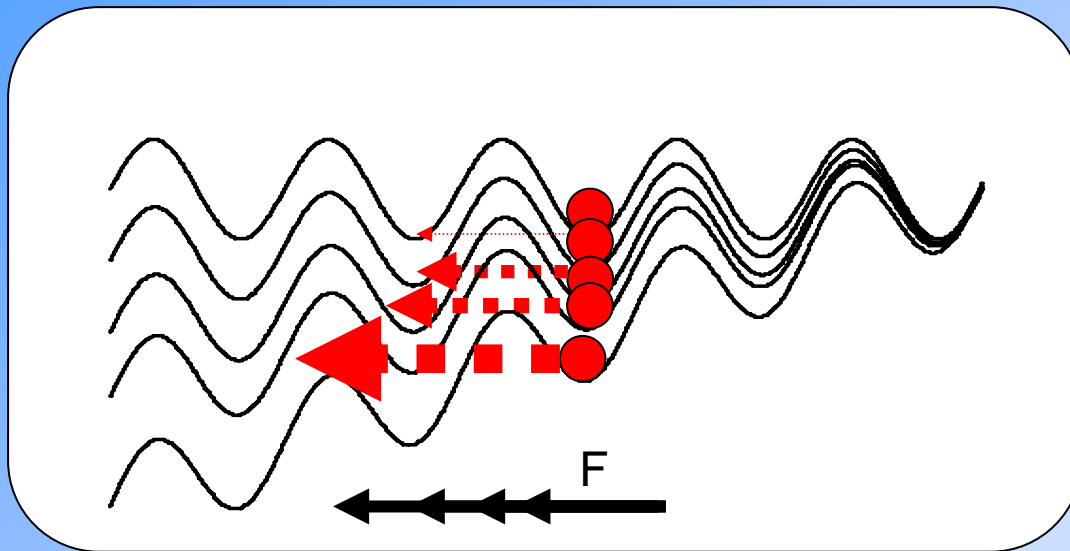
Oliver Morsch

CNR-INFM, Dipartimento di Fisica, Pisa

- Resonantly enhanced tunnelling (RET) - intro
- RET in the solid state
- RET in optical lattices
- Nonlinear effects
- Conclusions and outlook



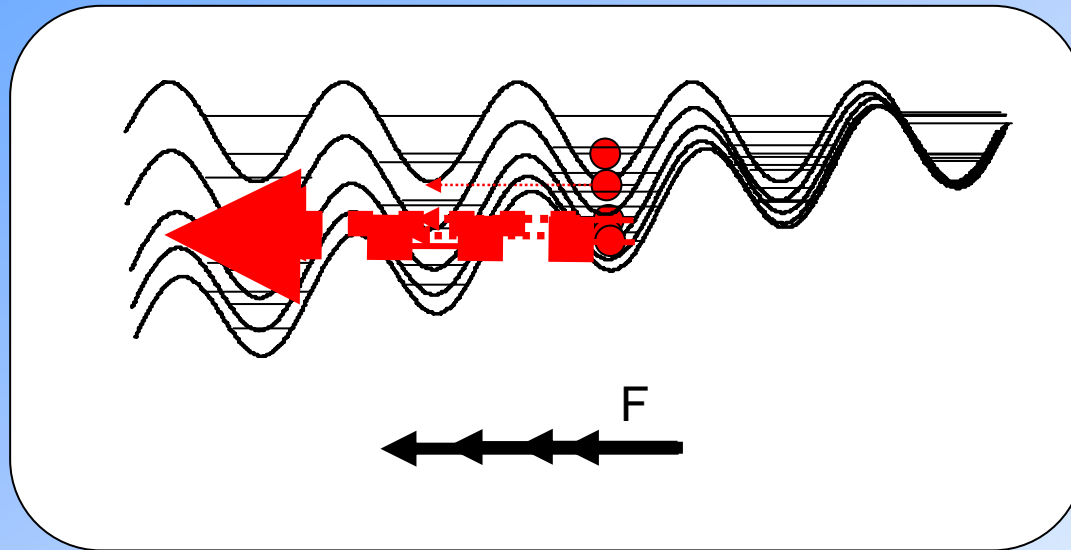
Tunnelling out of a potential well



Landau-Zener formula:

$$\Gamma_{\text{LZ}} \sim F \exp\left(-\frac{c}{d_L F}\right)$$

Resonantly enhanced tunnelling out of a potential well



Resonant tunnelling in superlattices

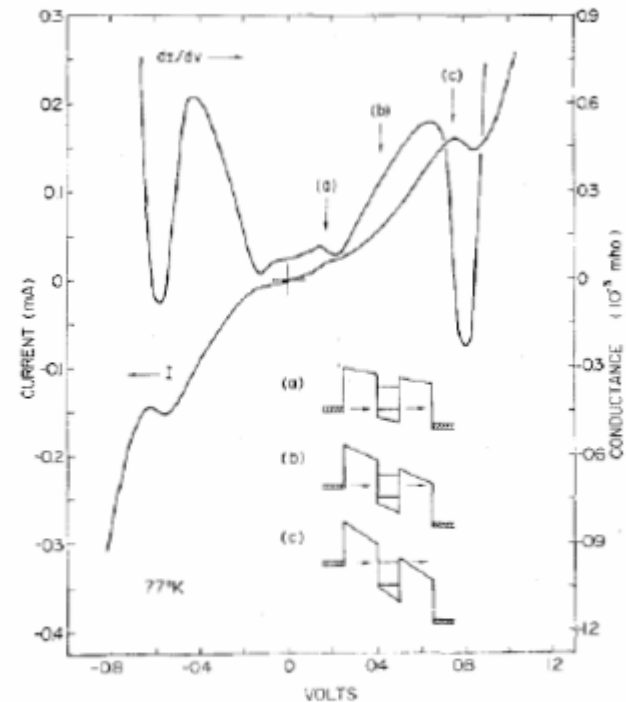
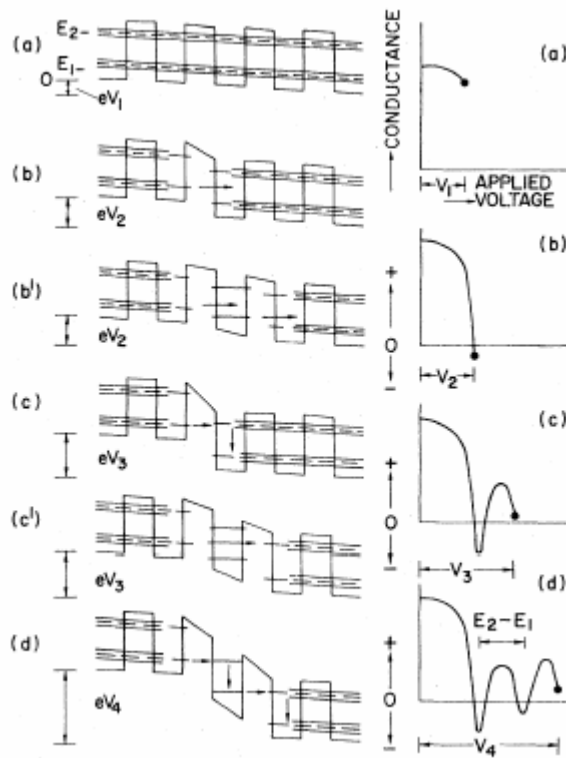


Fig. 6. Current-voltage and conductance-voltage characteristics of a double-barrier structure. Conditions at resonance (a), (c), and off-resonance (b), are indicated by arrows.

Resonant tunnelling in quantum dots

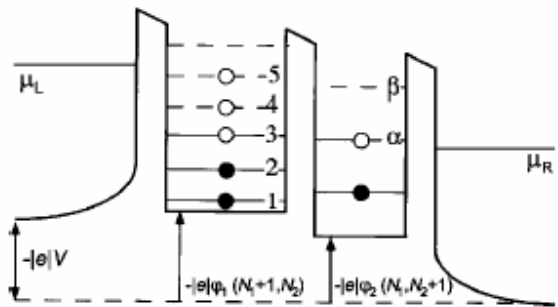
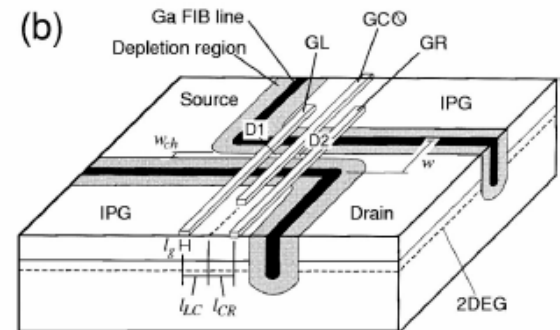
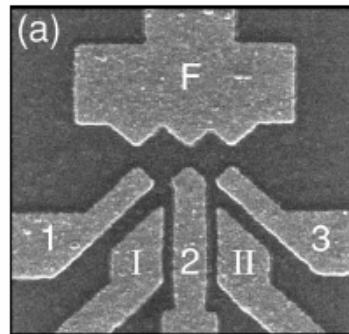


FIG. 14. Schematic potential landscape of the double quantum dot, where μ_L and μ_R denote the electrochemical potentials of the left and right reservoirs and V the bias voltage across the double dot. The 0D states in dot 1 are denoted by levels 1 to 5 and in dot 2 by levels α and β (from van der Vaart *et al.*, 1995).



Nobel Prize in Physics 1973: Tunnelling Phenomena



Leo Esaki

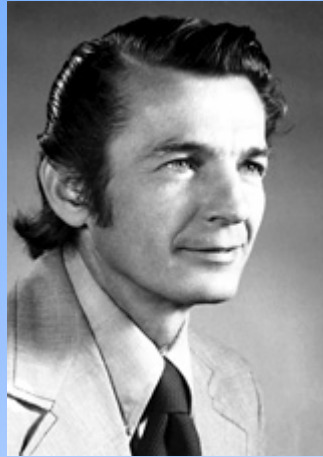
"for their experimental discoveries regarding tunneling phenomena in semiconductors and superconductors, respectively"

1/4 of the prize

Japan

IBM Thomas J. Watson
Research Center
Yorktown Heights, NY,
USA

b. 1925



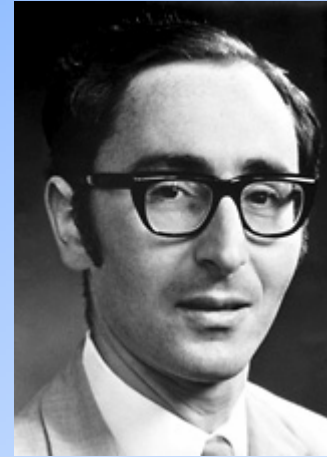
Ivar Giaever

1/4 of the prize

USA

General Electric
Company
Schenectady, NY, USA

b. 1929
(in Bergen, Norway)



Brian David Josephson

1/2 of the prize

United Kingdom

University of Cambridge
Cambridge, United
Kingdom

b. 1940

Who came up with the idea?

PHYSICAL REVIEW B

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Coherent versus incoherent resonant tunneling in high- T_c cuprates

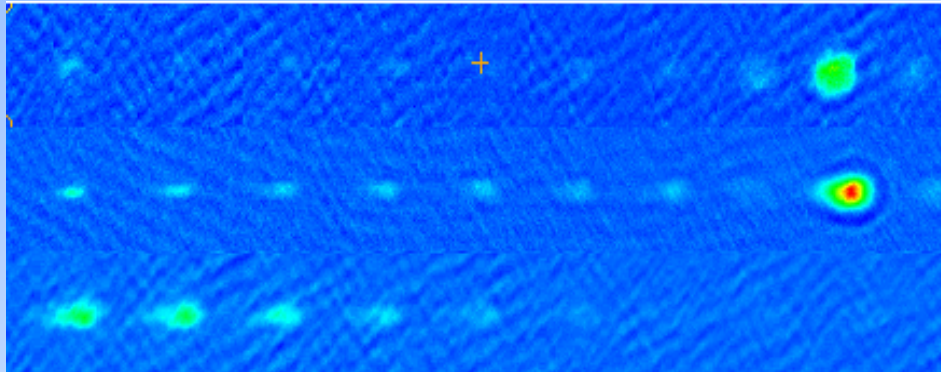
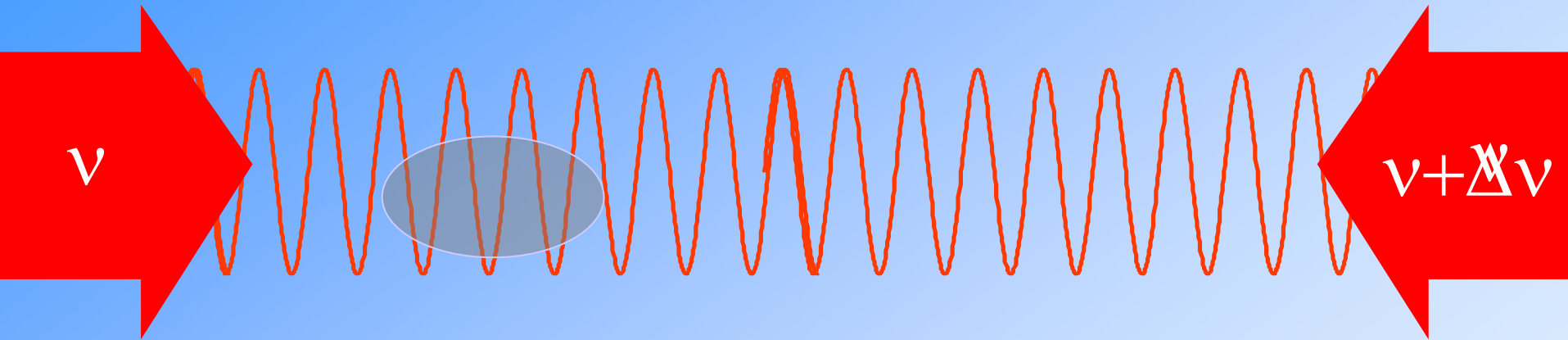
A. A. Abrikosov

Materials Science Division, Argonne National Laboratory, 9700 South Cass Avenue, Argonne, Illinois 60439
(Received 21 April 1997)

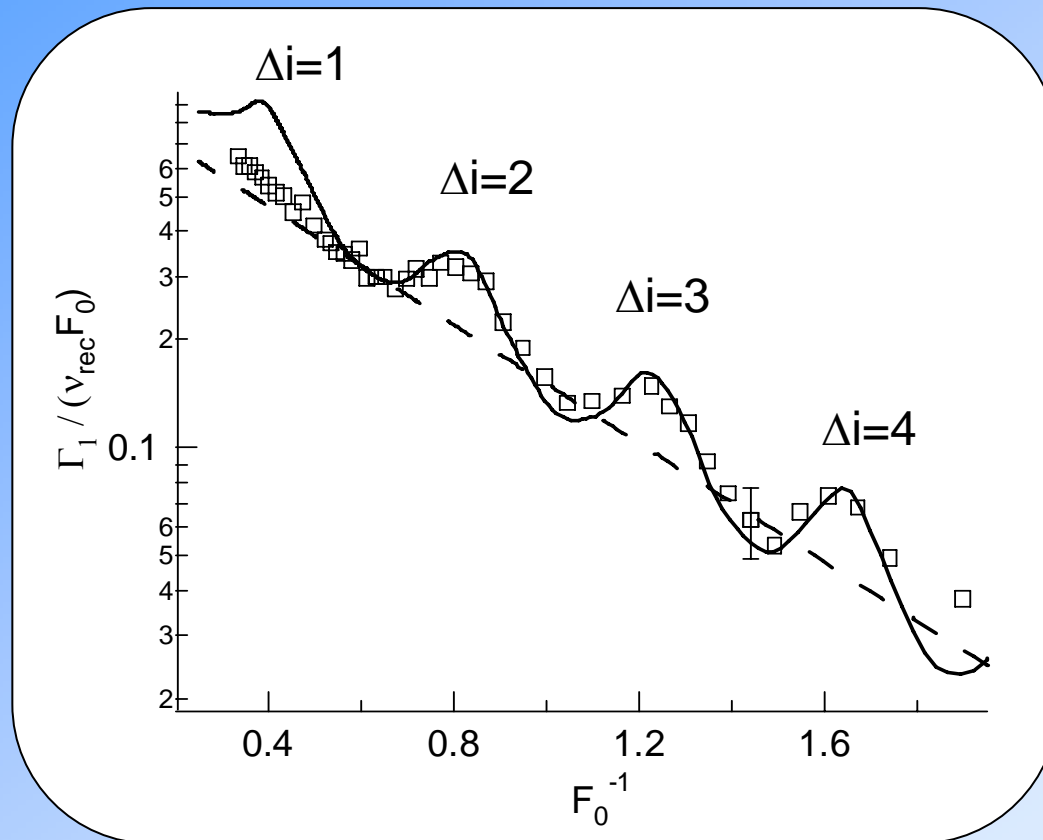
one. In order for this mechanism to be effective, it should correspond to “resonance tunneling” discovered by Bohm in 1951.⁷ This phenomenon happens under two conditions:

⁷D. Bohm, *Quantum Theory* (Prentice Hall, New York, 1951).

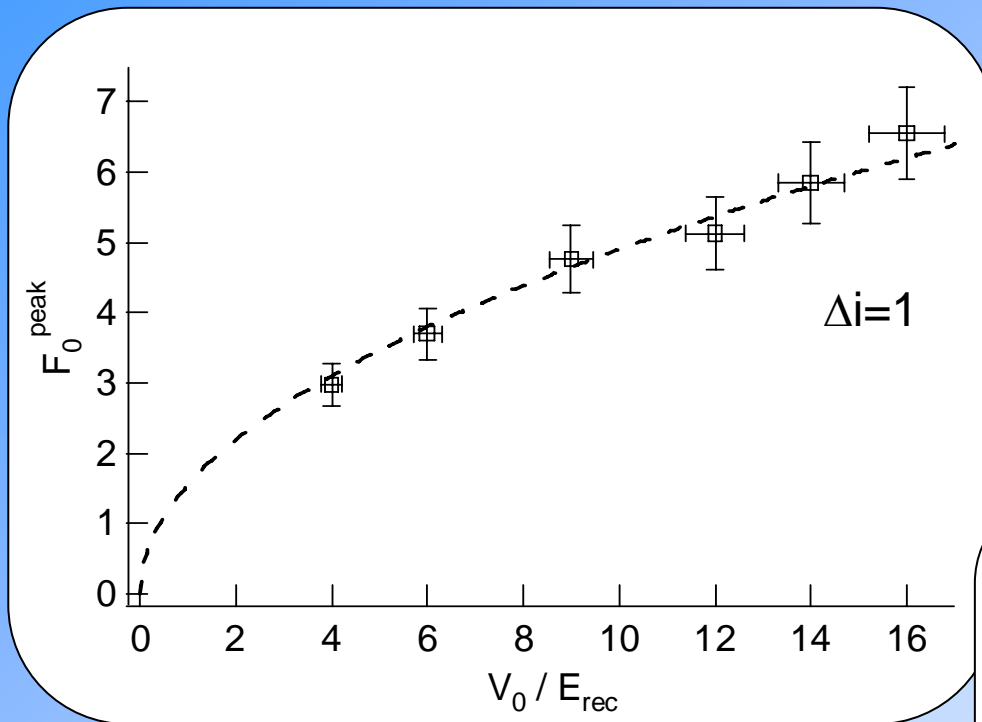
BEC in an accelerated lattice



The experiment – resonant tunnelling in optical lattices



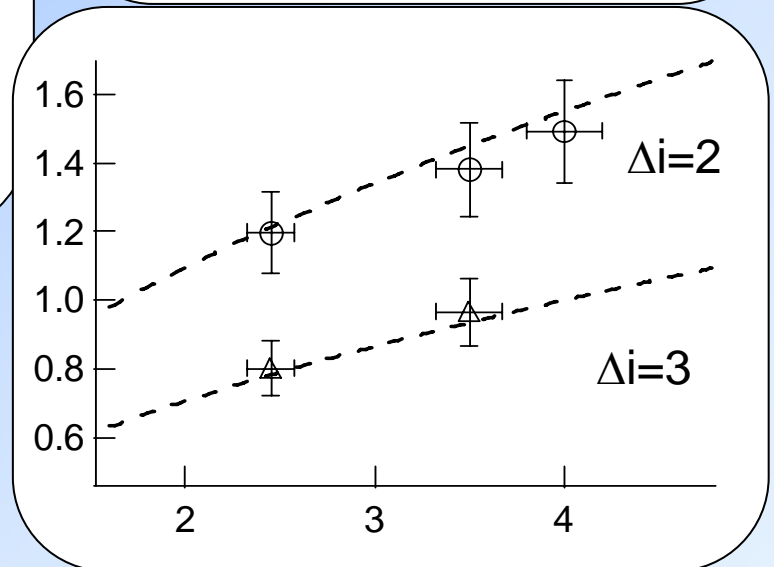
Positions of resonances – harmonic approximation



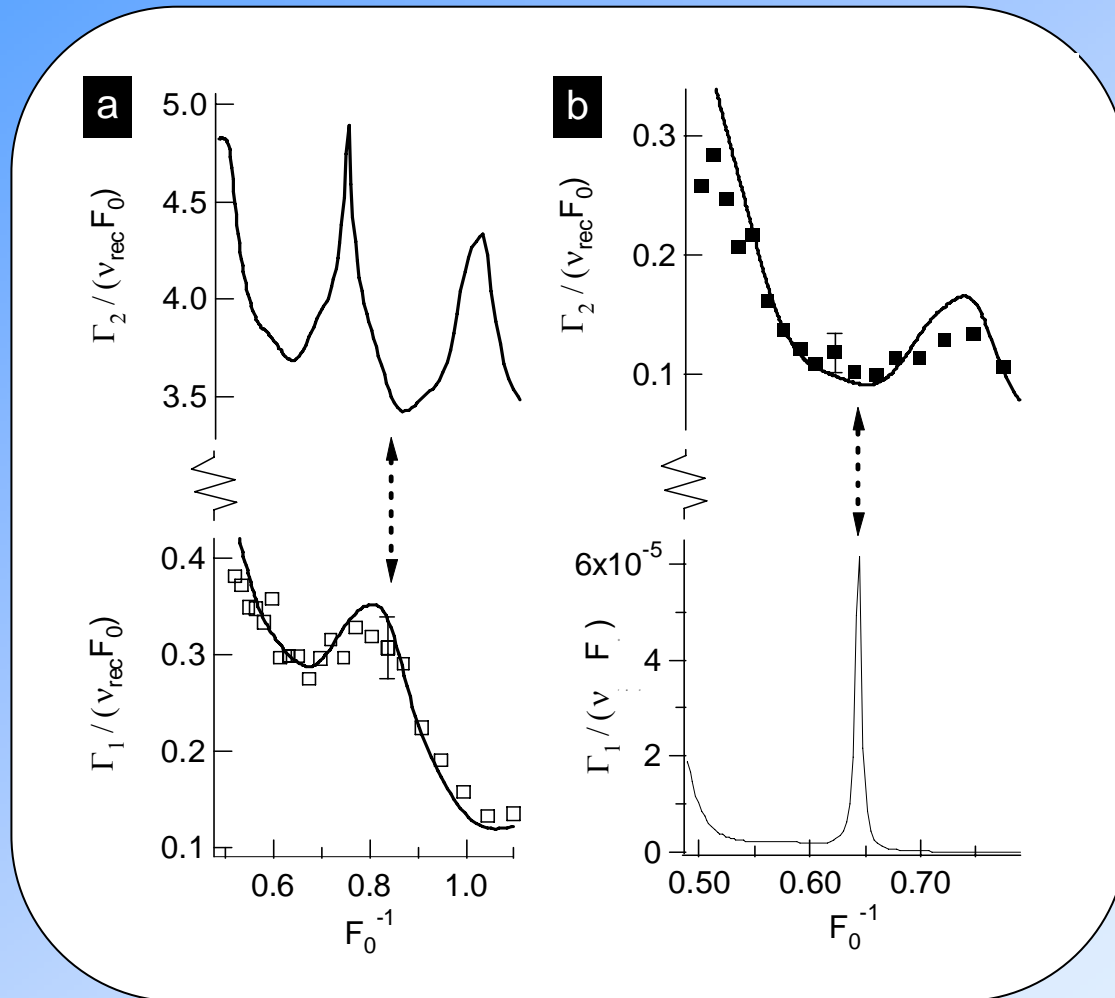
harmonic approximation:

$$\Delta E = \alpha E_{\text{rec}} \sqrt{V_0/E_{\text{rec}}}$$

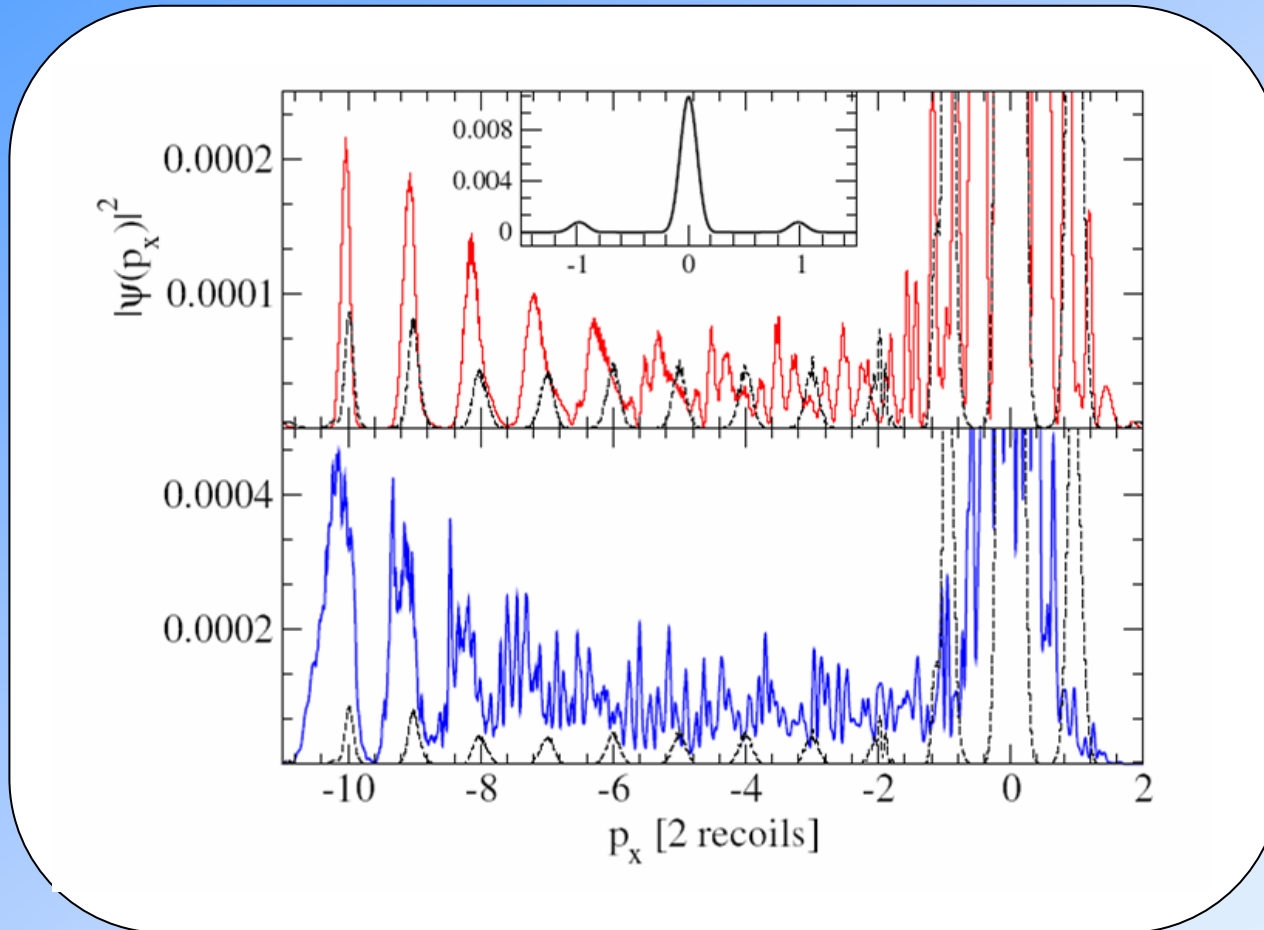
Find agreement with data for $\alpha=1.5$ (to be compared with $\alpha=2$ for perfectly harmonic potential)



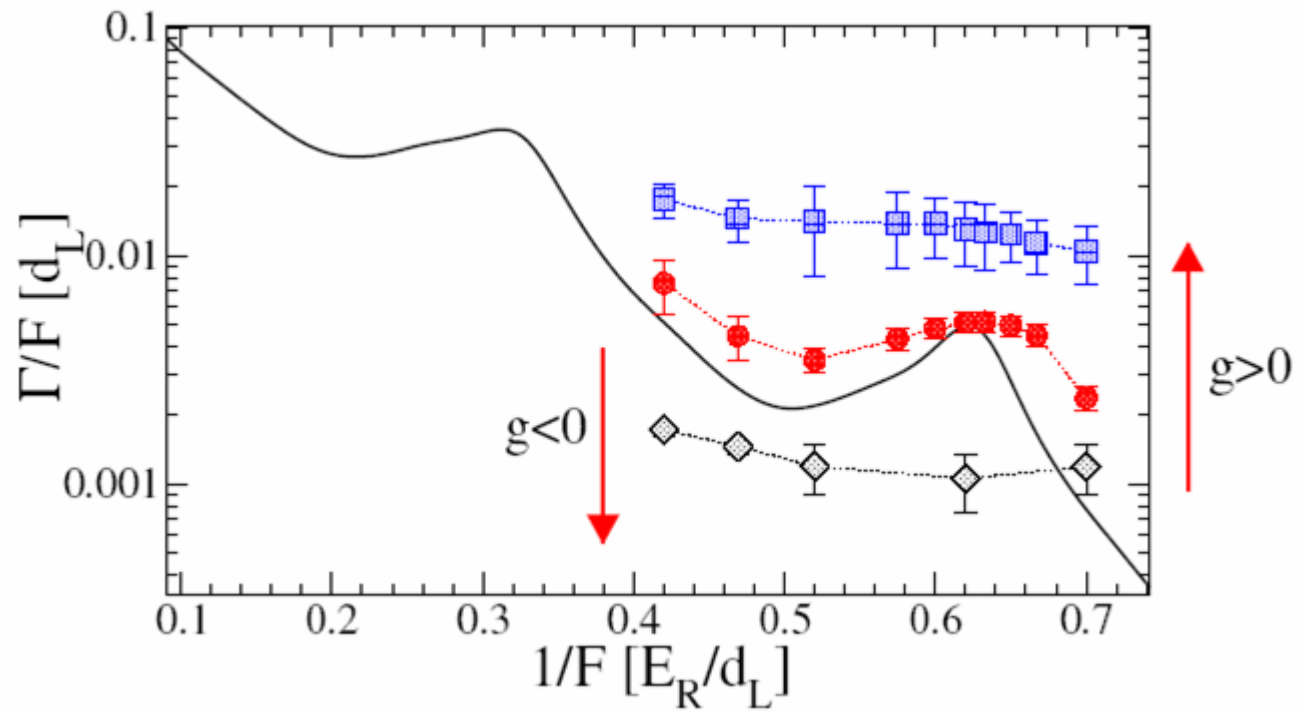
Resonances in higher energy levels – crossing scenarios



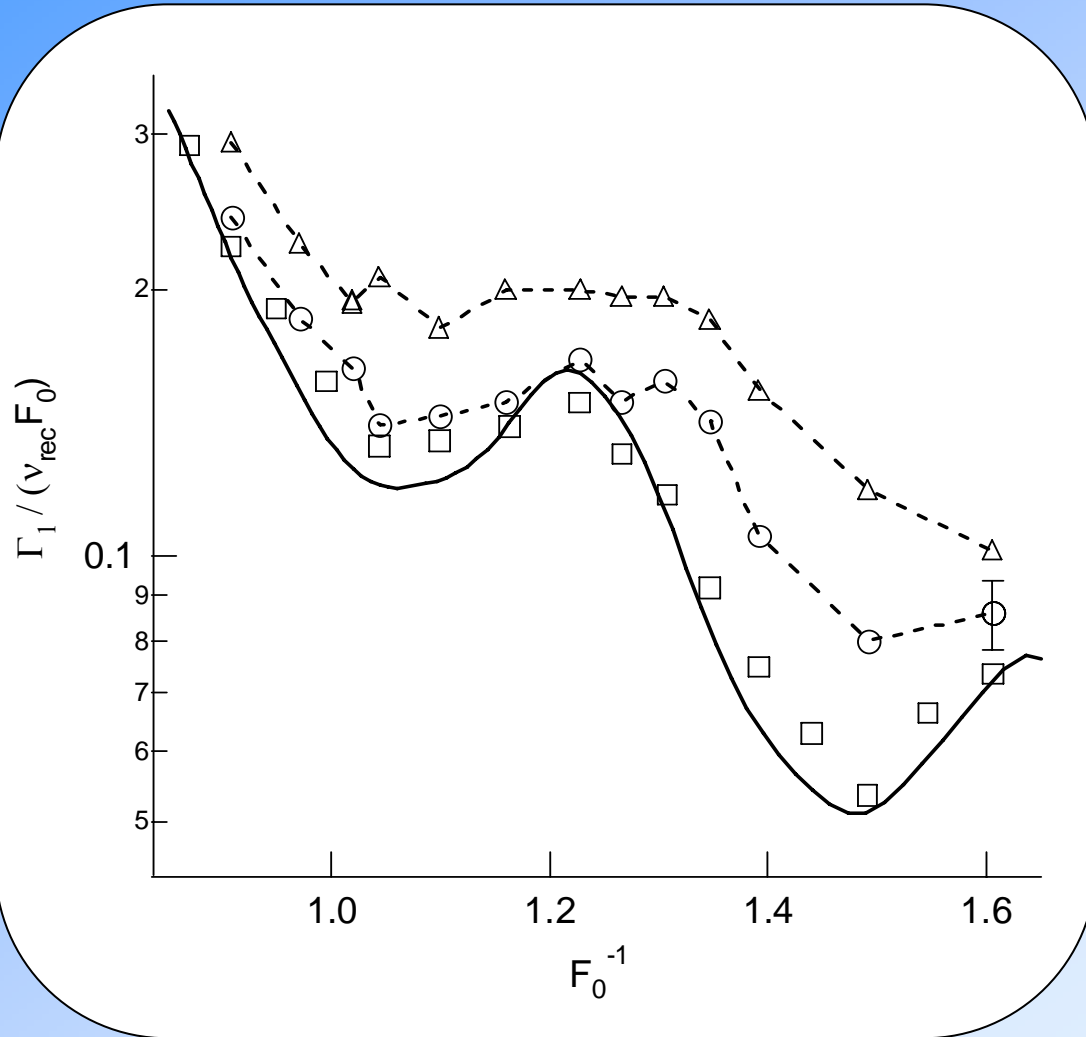
Nonlinear RET



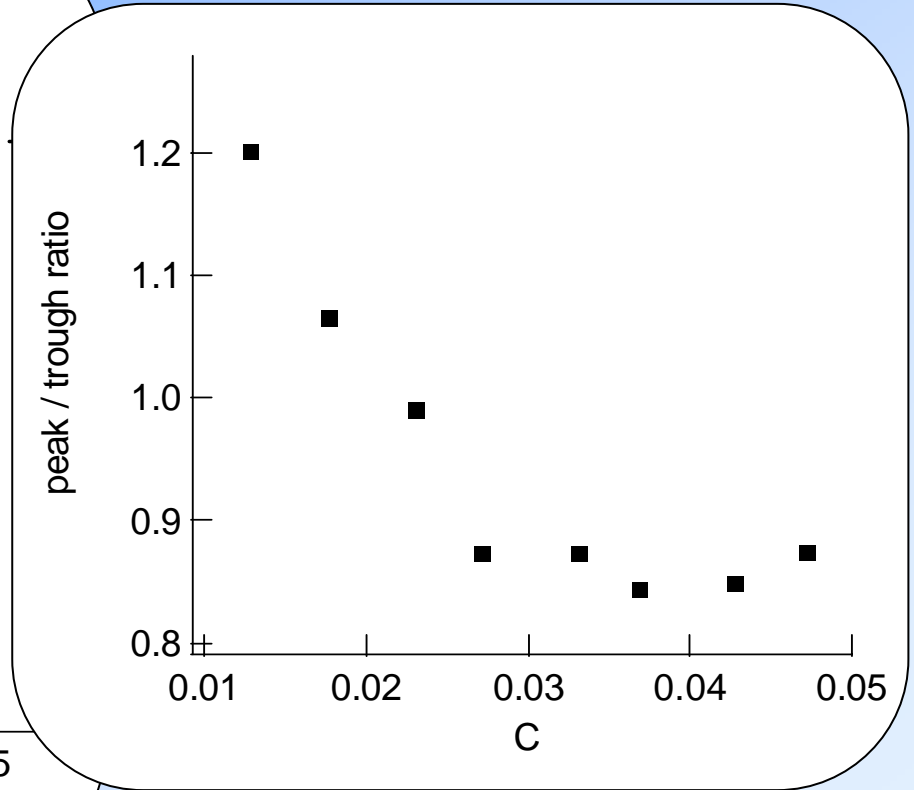
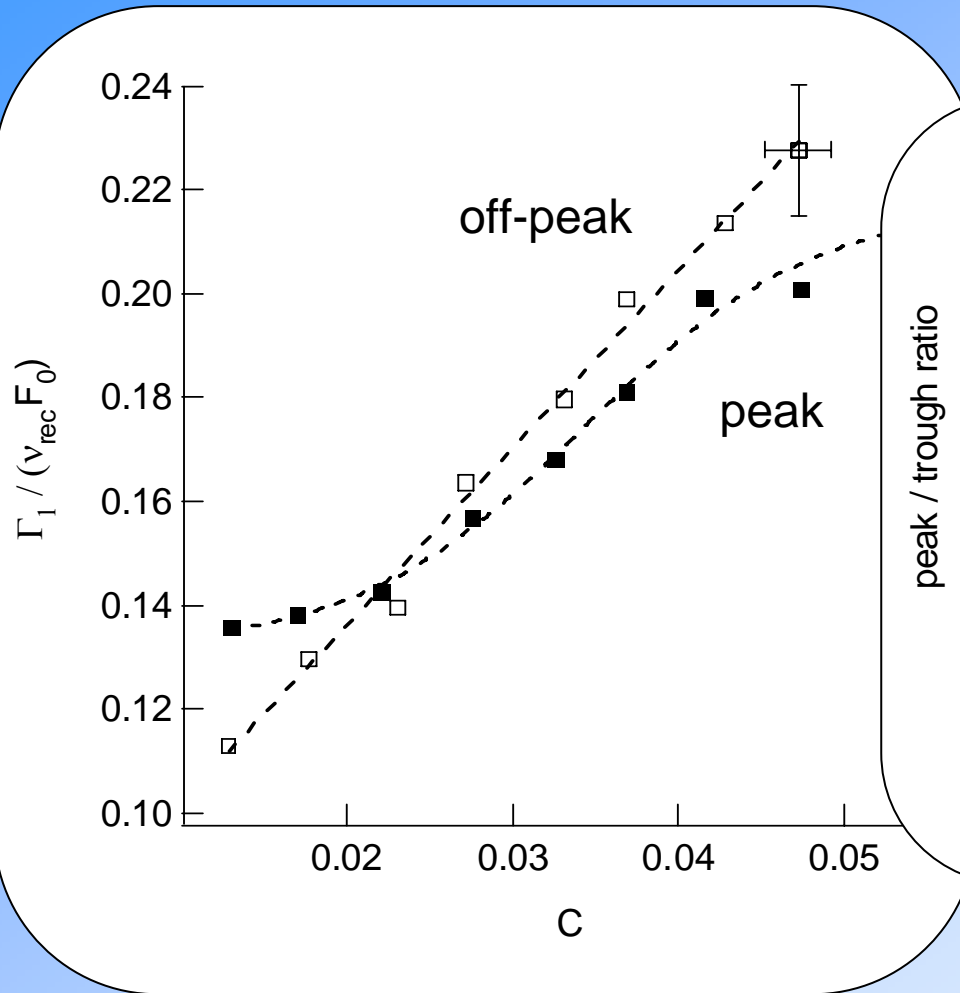
Nonlinear RET



Nonlinear RET



Nonlinear RET

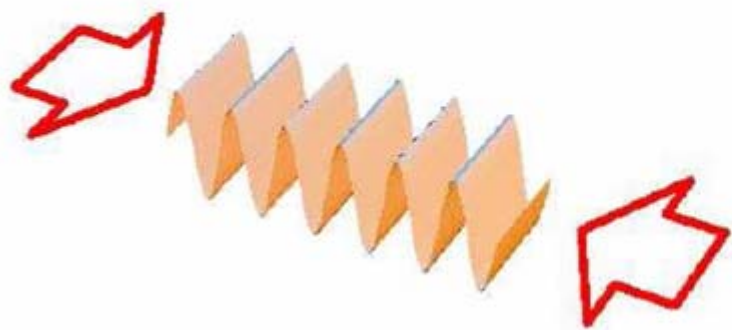


Conclusions and outlook

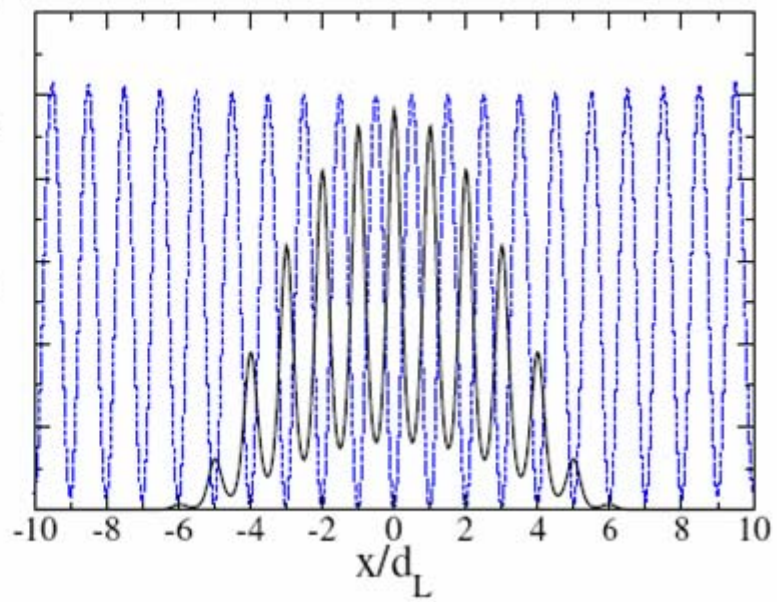
- BECs in optical lattices are a flexible system for investigating resonant tunnelling phenomena
- possibility to add noise (global and local), disordered potentials, thermal fraction
- narrow resonances in deep potentials might be interesting for precision measurements
- any other ideas?

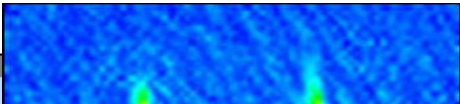
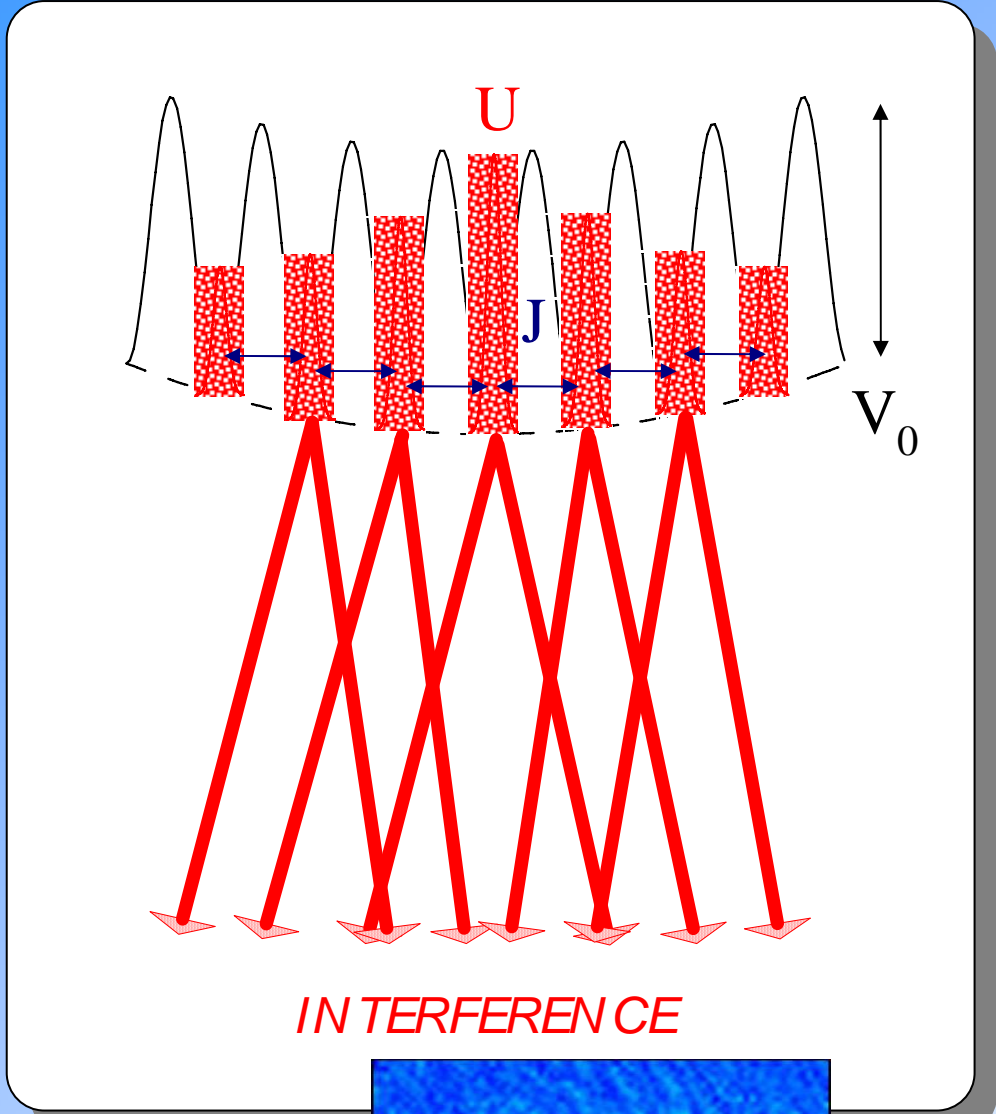
The team





initial state [arbitrary units]



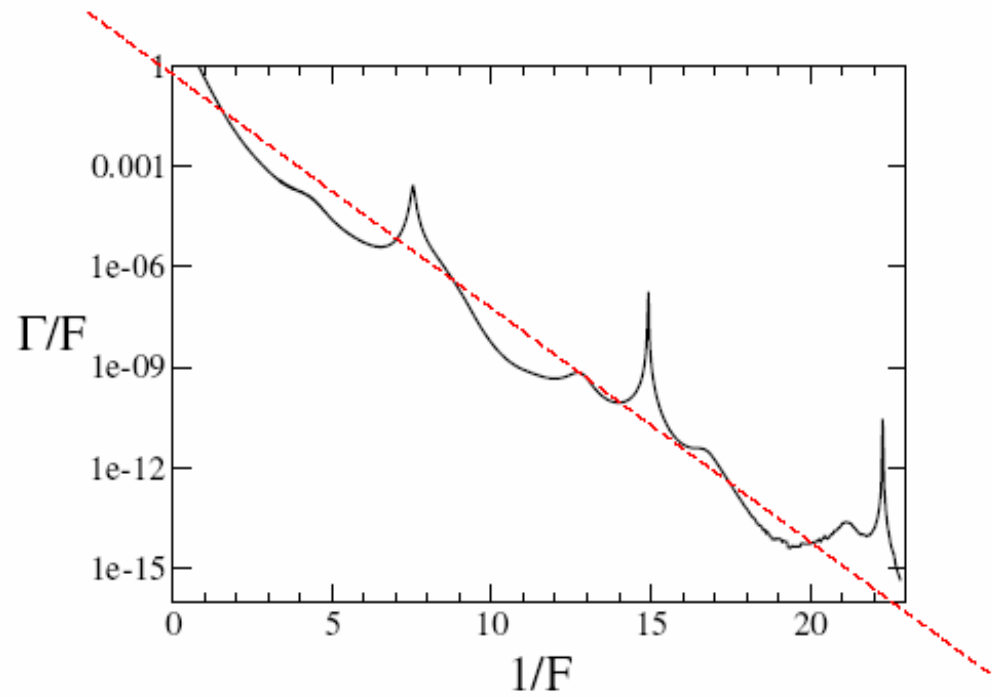


Landau-Zener tunnelling

Decay via inter-band tunnelling after each Bloch period $T_B = 2\pi\hbar/d_L F$:

$$\Gamma_{LZ} \sim F \exp\left(-\frac{c}{d_L F}\right)$$

with constant $c \approx (\text{band gap})^2 \approx V_0^2$



[e.g. Glück, Kolovsky, Korsch, Phys. Rep. (2002)]