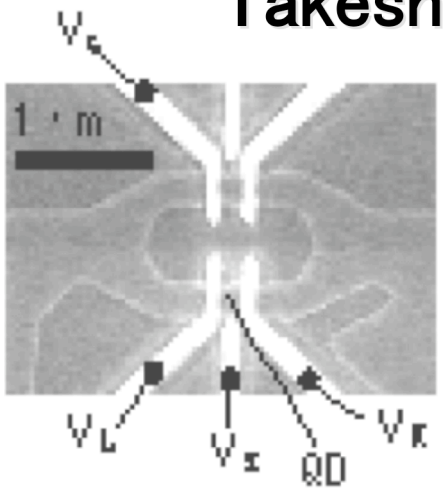
Title: Persistence of Fano and Aharonov-Bohm phases in an interferometer with a quantum dot

Takeshi Nakanishi, Kiyoyuki Terakura (AIST)
and Tsuneya Ando (TIT)



PRB 69, 115307 (2004)

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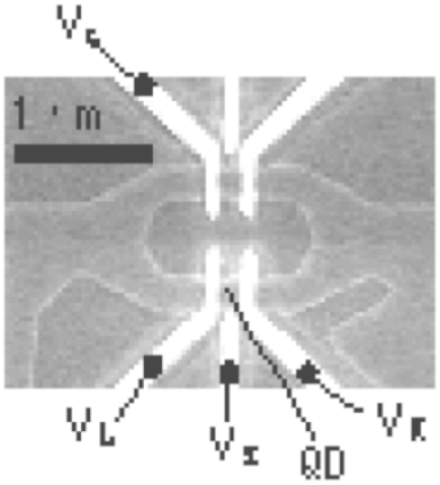
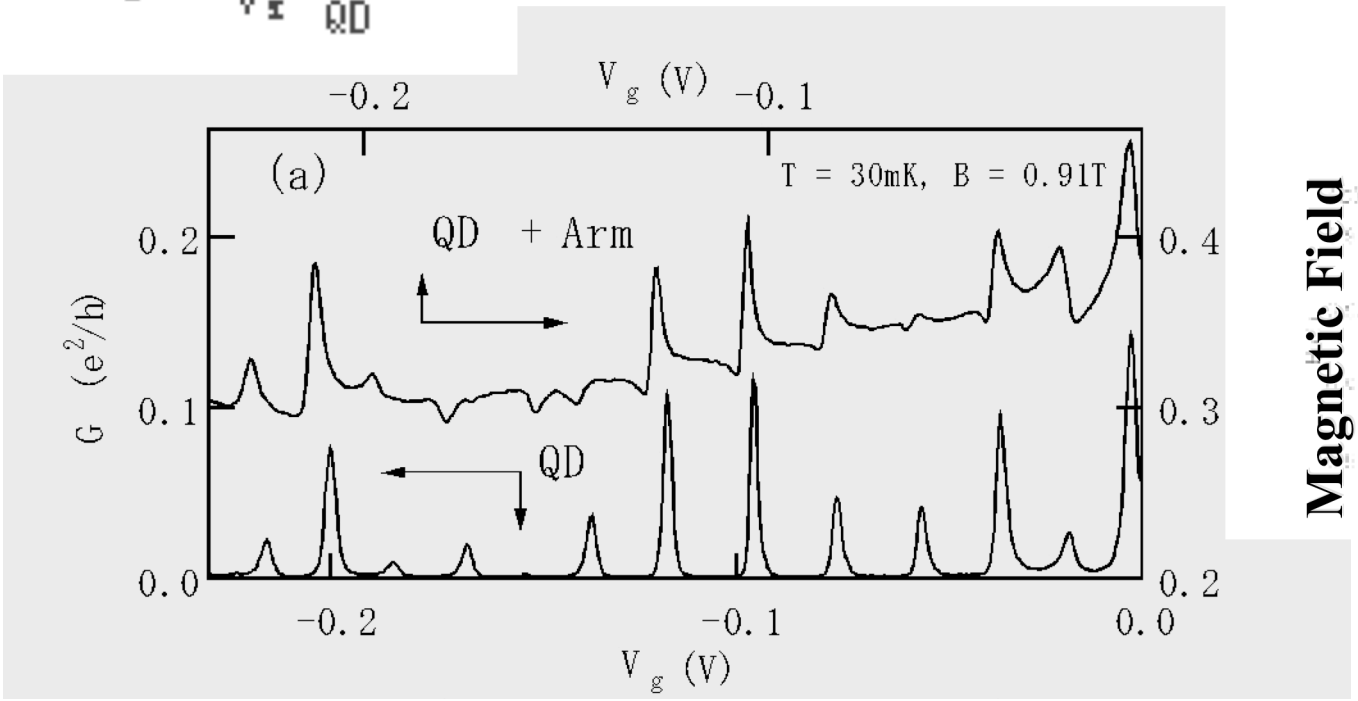
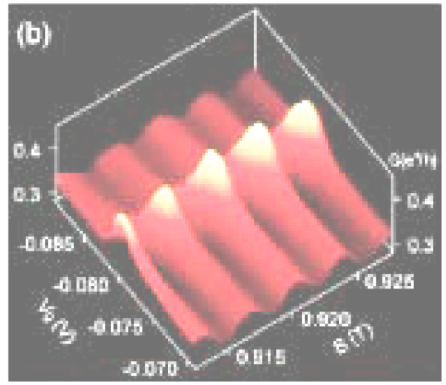
Experiment

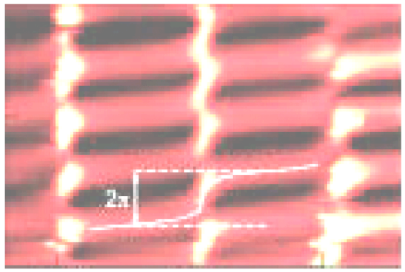
Kobayashi, Aikawa, Katsumoto, Iye, PRL 88 (2002) 256806.

- Fano (Asymmetric) line-shape
- 2π shift in AB Oscillation









Magnetic Field

Gate Voltage

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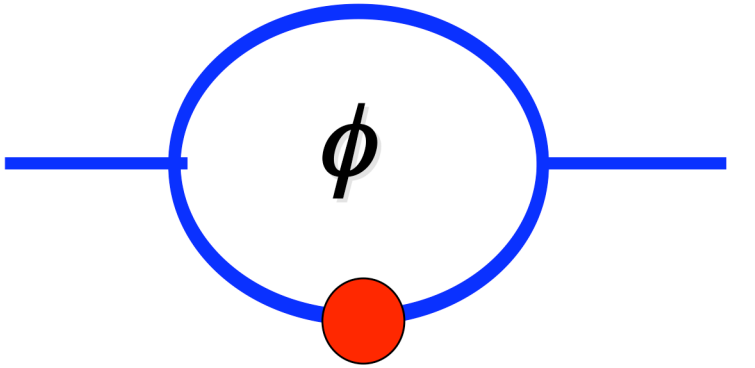
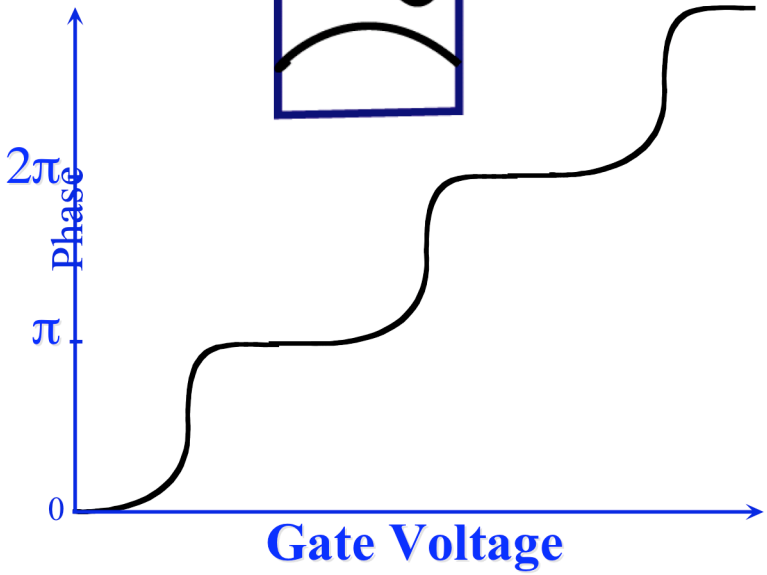
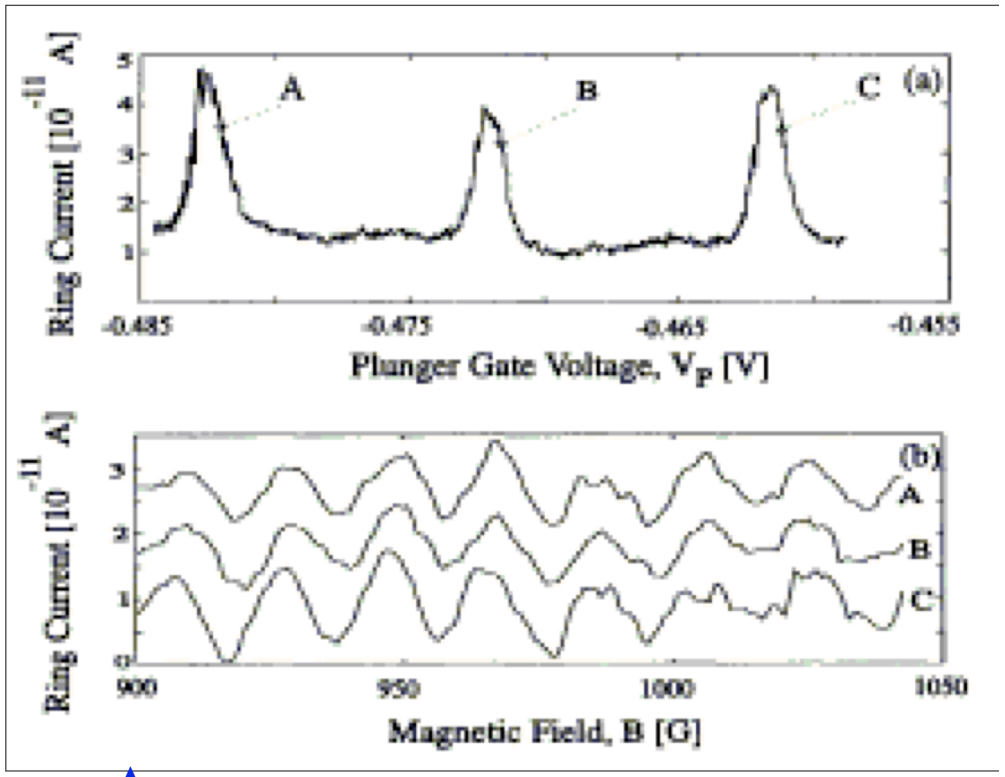
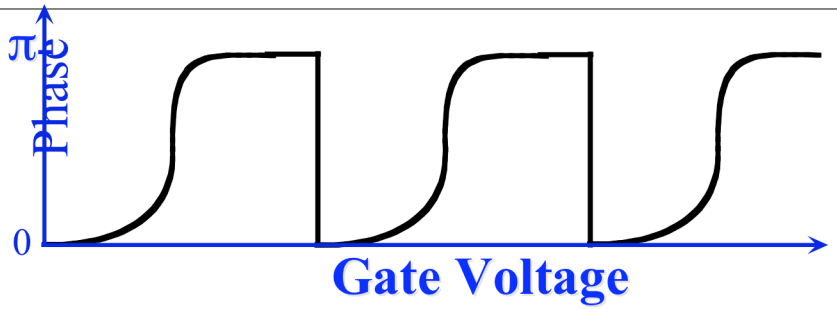
AB Phase





Yacoby *et al.* 1995, Schuster *et al* .1997





Fano effects (U. Fano PR **124** (1961) 1866)

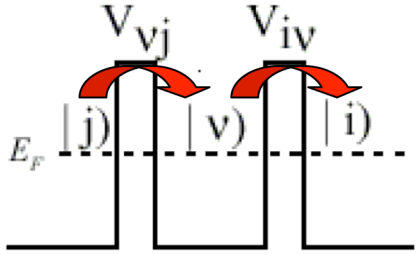
Transmission coefficients through QD

$$t^d_{ij} = \frac{\alpha_{ij}}{\epsilon + \mathrm{i}}$$

(Breit-Wigner) with

$$\begin{aligned} \alpha_{ij} &= -2\pi \mathrm{i} V_{i\nu}(E) V_{\nu j}(E) D(E)/\Gamma, \\ \epsilon &= (E - E_\nu - F)/\Gamma, \end{aligned}$$

Level shift F and width Γ



Phase information may be gotten from interference effects; AB and Fano effect.

Double-slit condition

$$t_{ij} = t^0_{ij} + t^d_{ij},$$

t^0_{ij}: continuum (constant)

$$\frac{|t_{ij}|^2}{|t^0_{ij}|^2} = \frac{|\epsilon + q_{ij}|^2}{\epsilon^2 + 1},$$

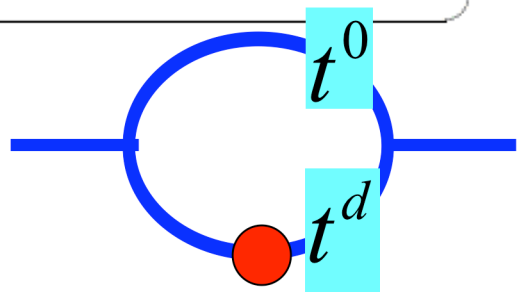
with

$$q_{ij} = \frac{\alpha_{ij}}{t^0_{ij}} + \mathrm{i}.$$

Conductance

$$G = \frac{e^2}{\pi\hbar} T_0 \frac{|\epsilon + q|^2}{\epsilon^2 + 1},$$

$$q = q' + iq''$$



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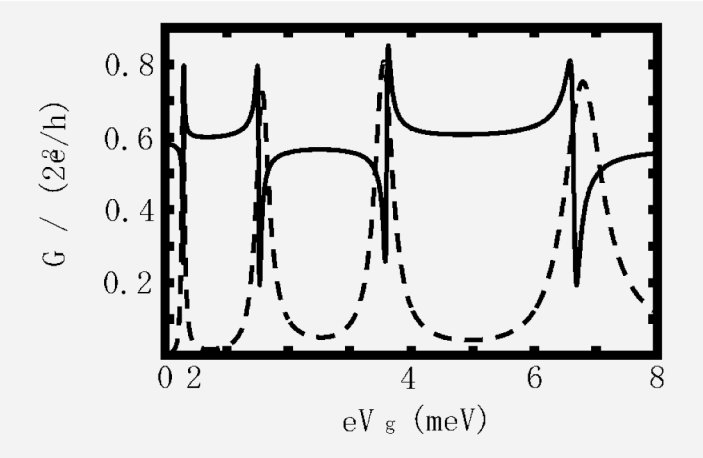
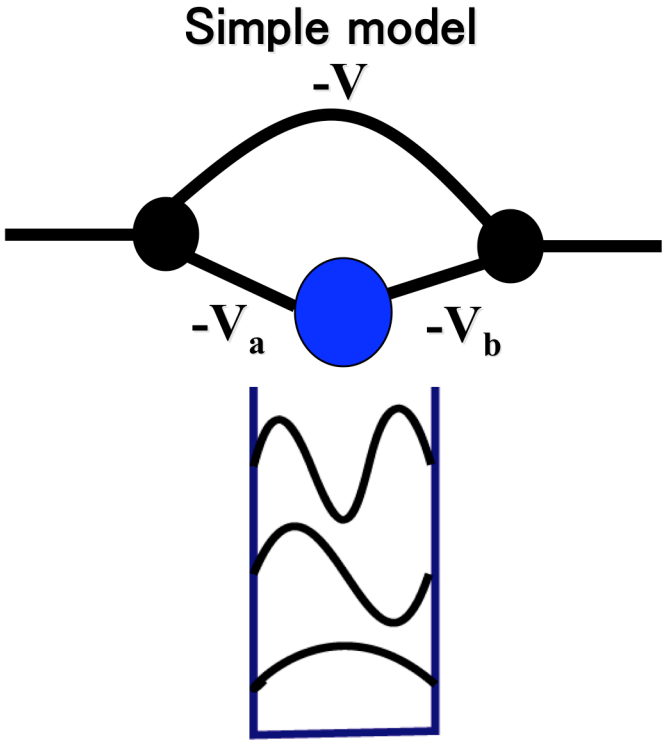
Fano & AB in 1D Model

Alternative Fano q & π shift in AB

Entin-Wohlman, *et al.*, J. Low. Temp. Phys. 126 (2002) 1251

Ueda, *et al.*, J. Phys. Soc. Jpn 72 Suppl. A (2003) 157





	Fano q	AB
1D Model	+−+−	π
Experiment	++++	2π

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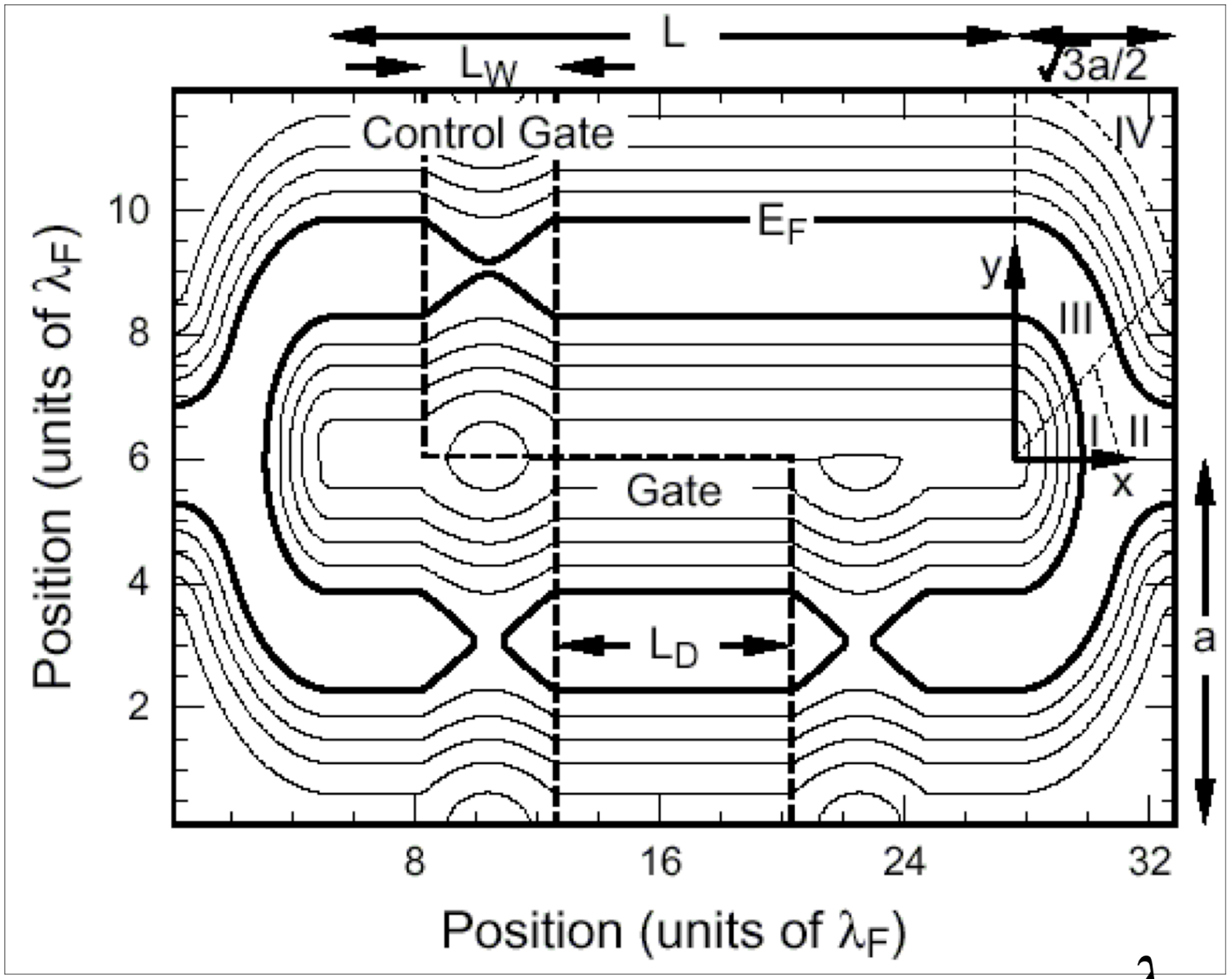
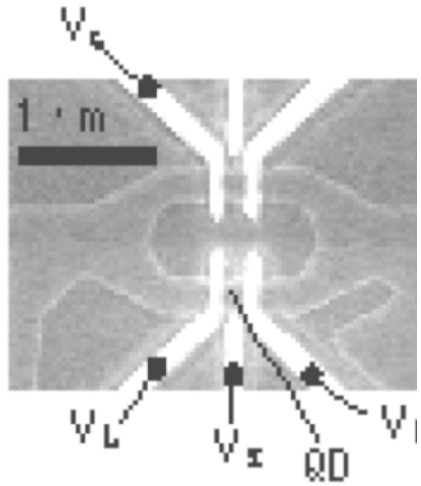
Realistic Model (Equi-potential lines)





3 channels in arms and leads

λ_F Fermi wave length

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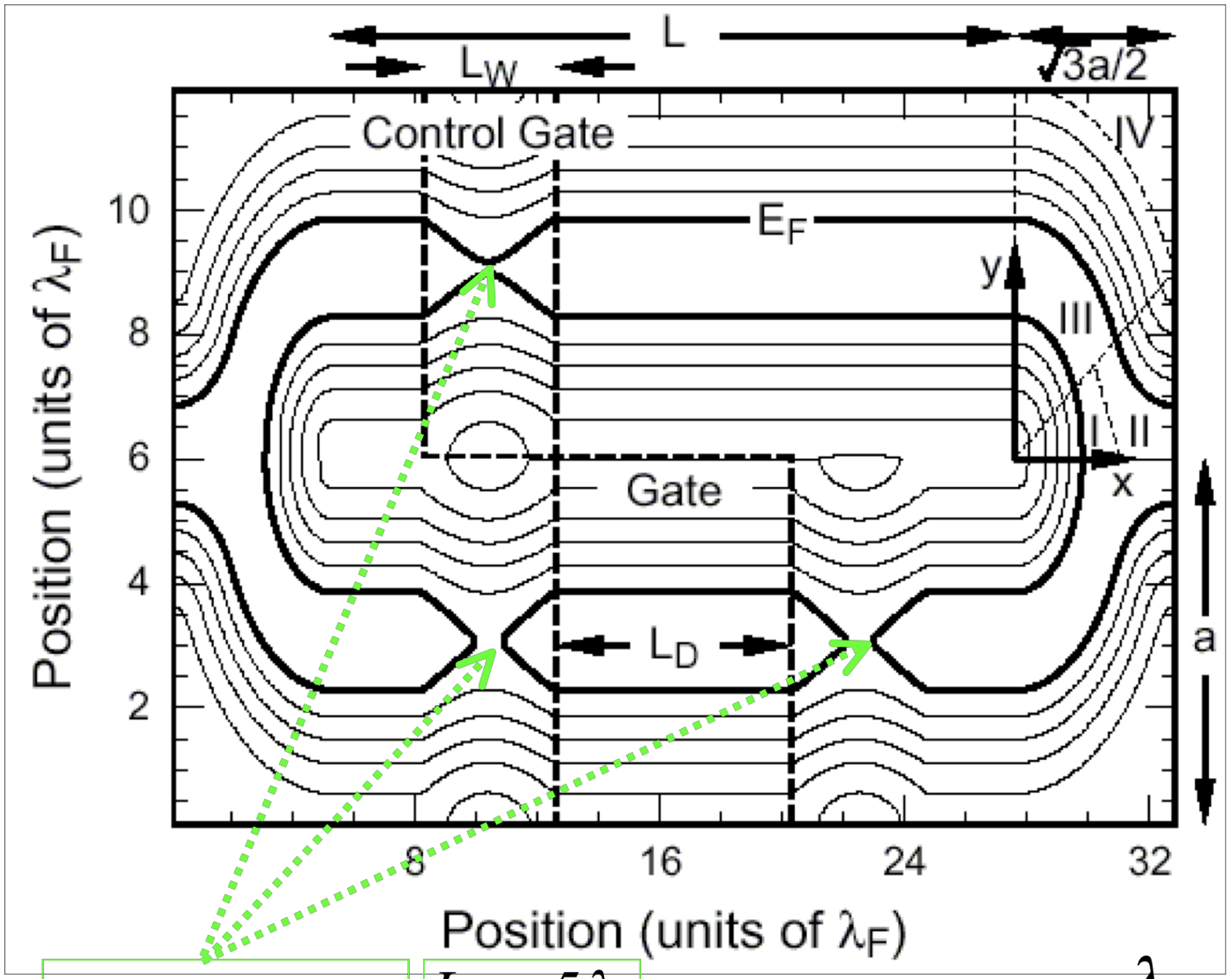
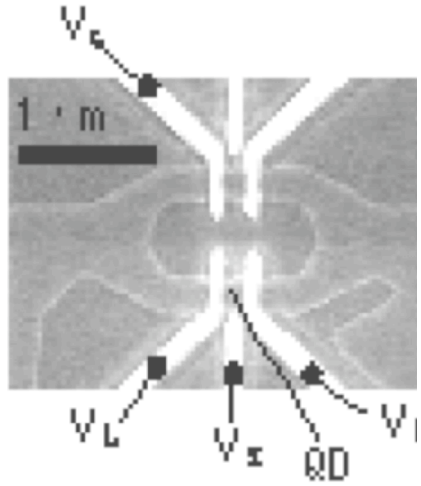
Realistic Model (Equi-potential lines)





3 channels in arms and leads

Adiabatic Walls $L_w = 5\lambda_F$

λ_F **Fermi wave length**

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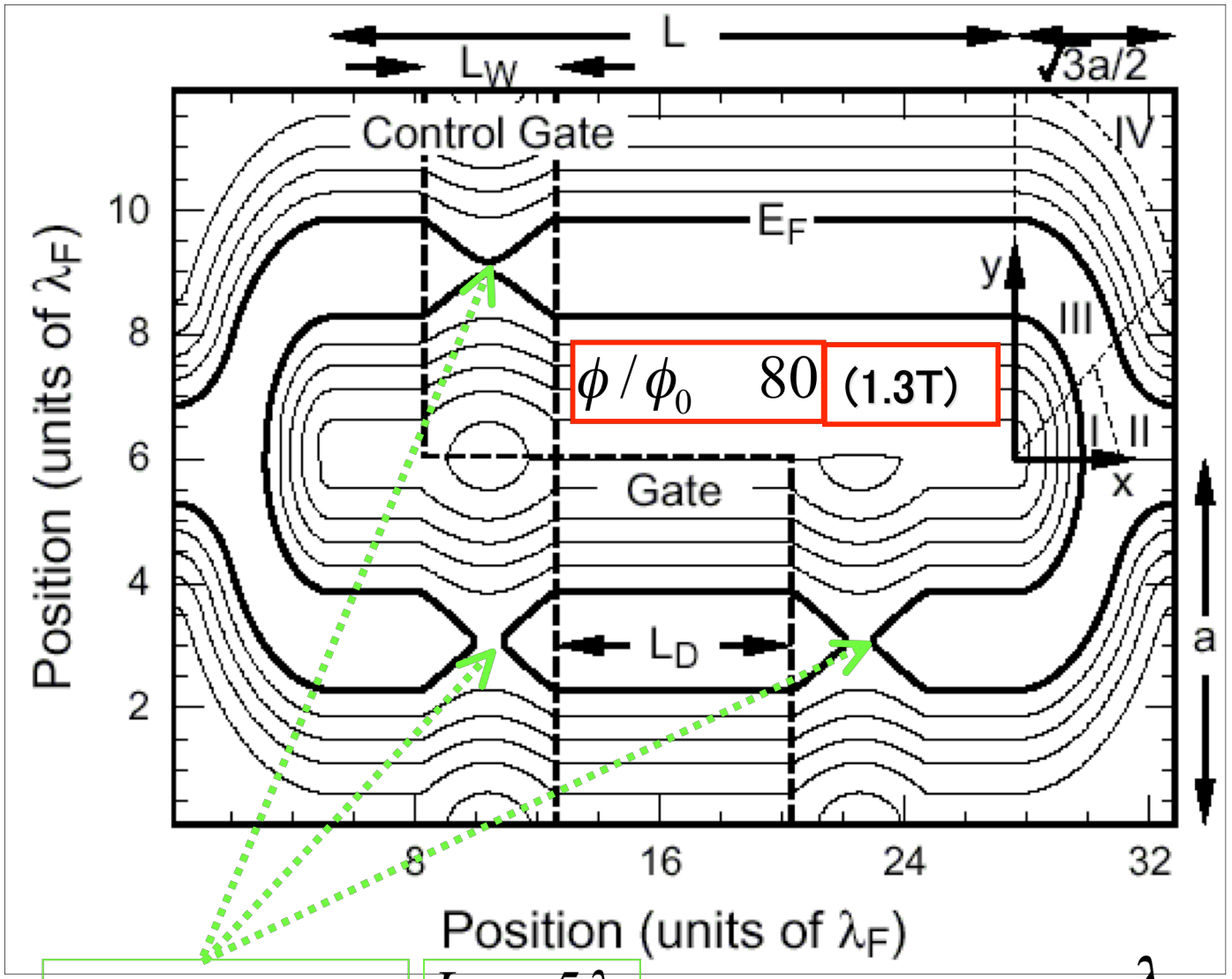
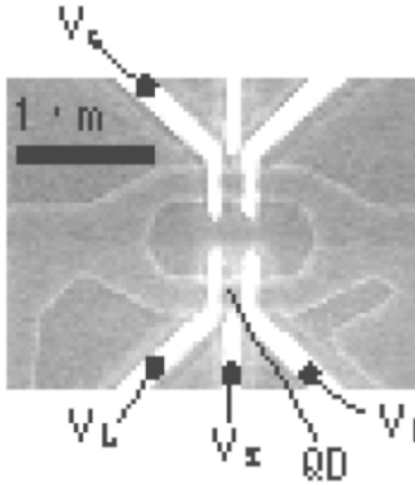
Realistic Model (Equi-potential lines)





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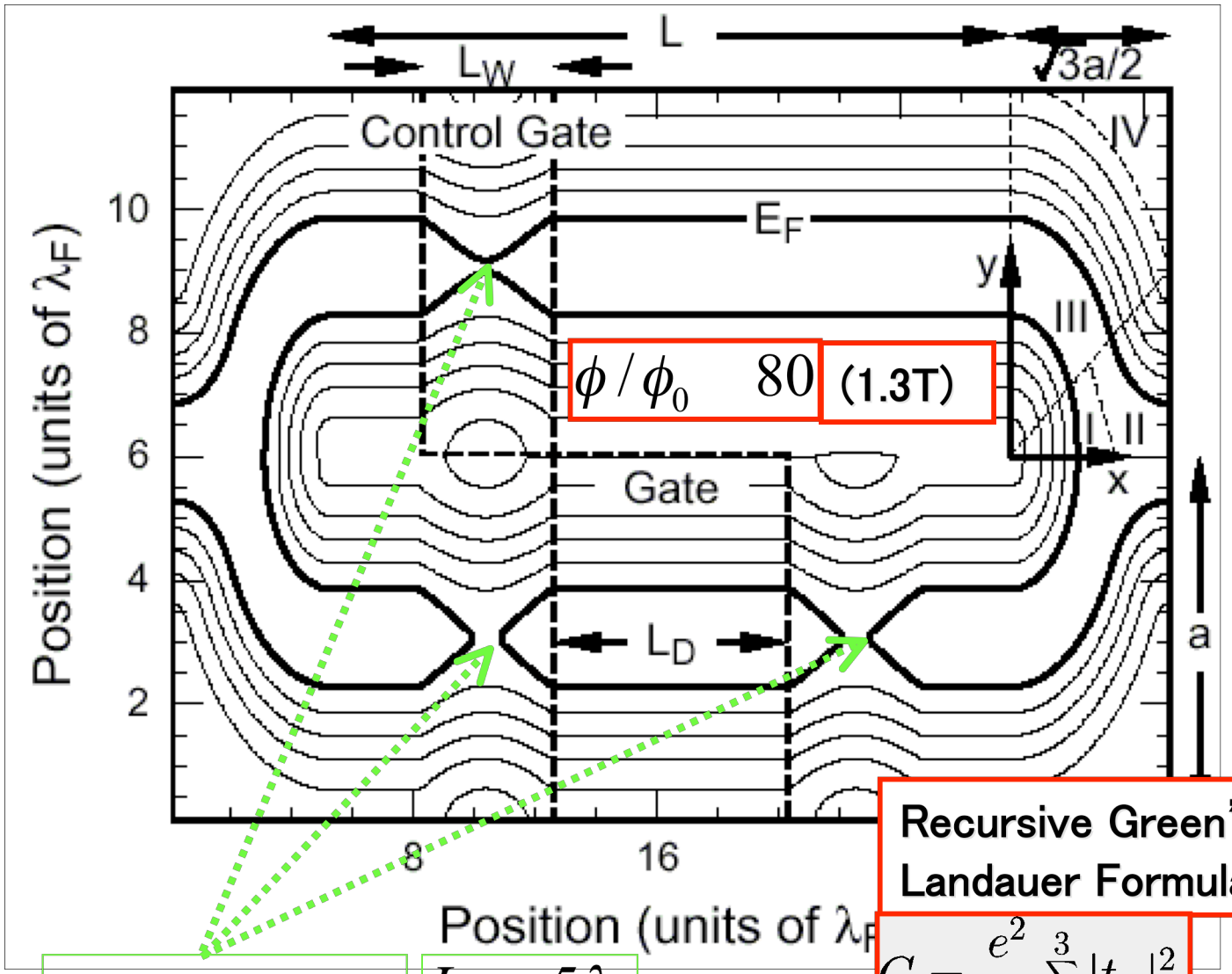
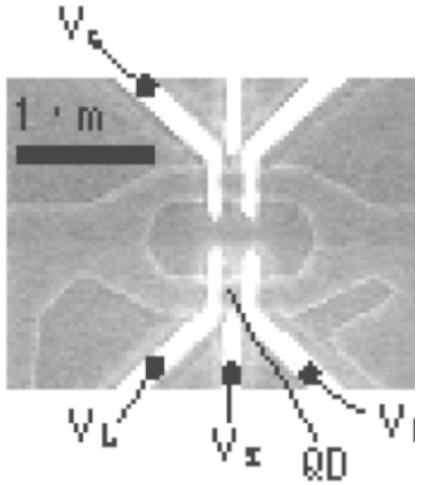




3 channels in arms and leads

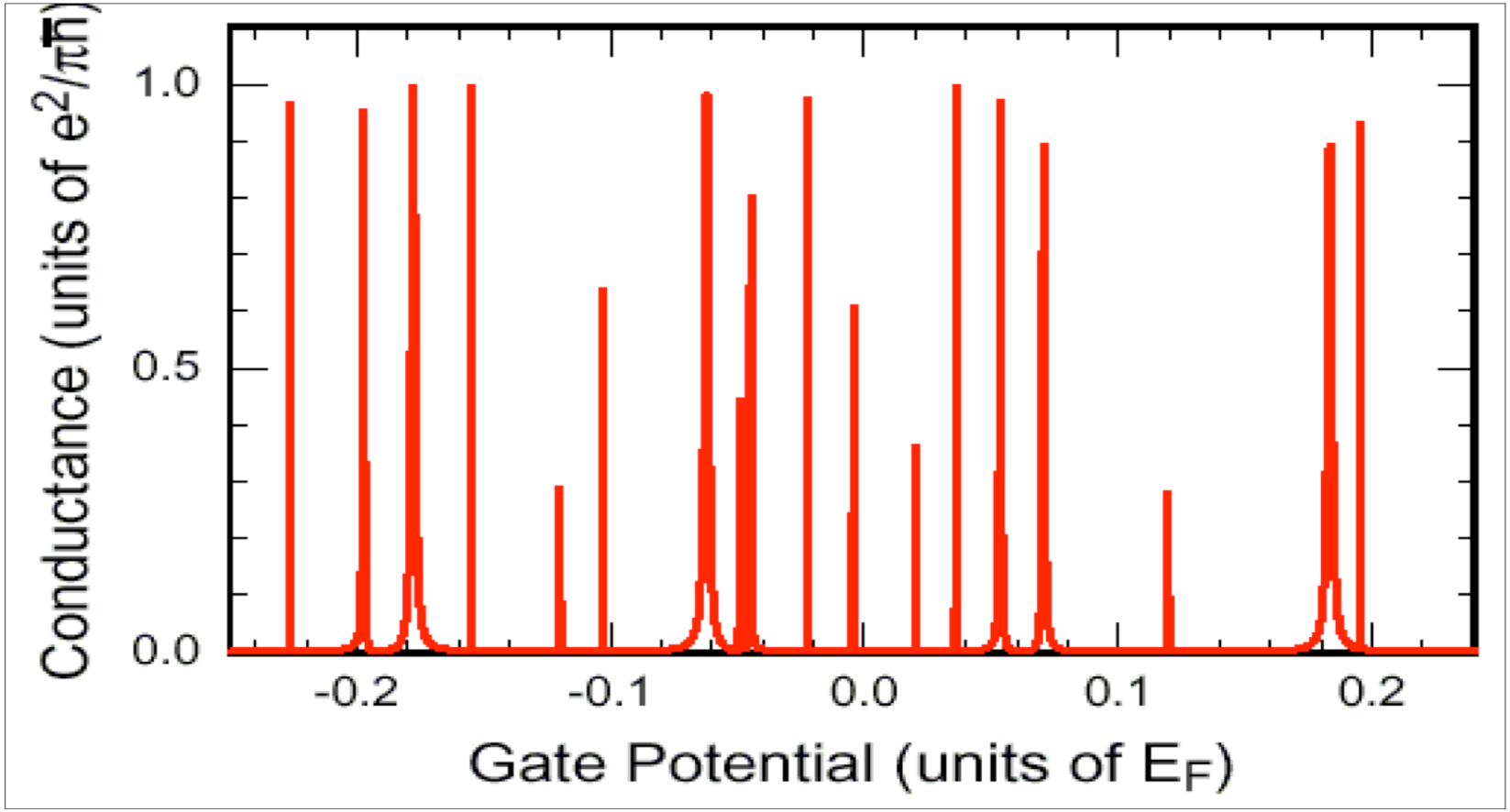
Recursive Green's function method
Landauer Formula

$$G = \frac{e^2}{\pi\hbar}\sum_{ij}^{3}|t_{ij}|^2.$$

Adiabatic Walls $L_w = 5\lambda_F$

Fermi wave length

Asymmetry in sequence



- AB ring
- Pinched Off

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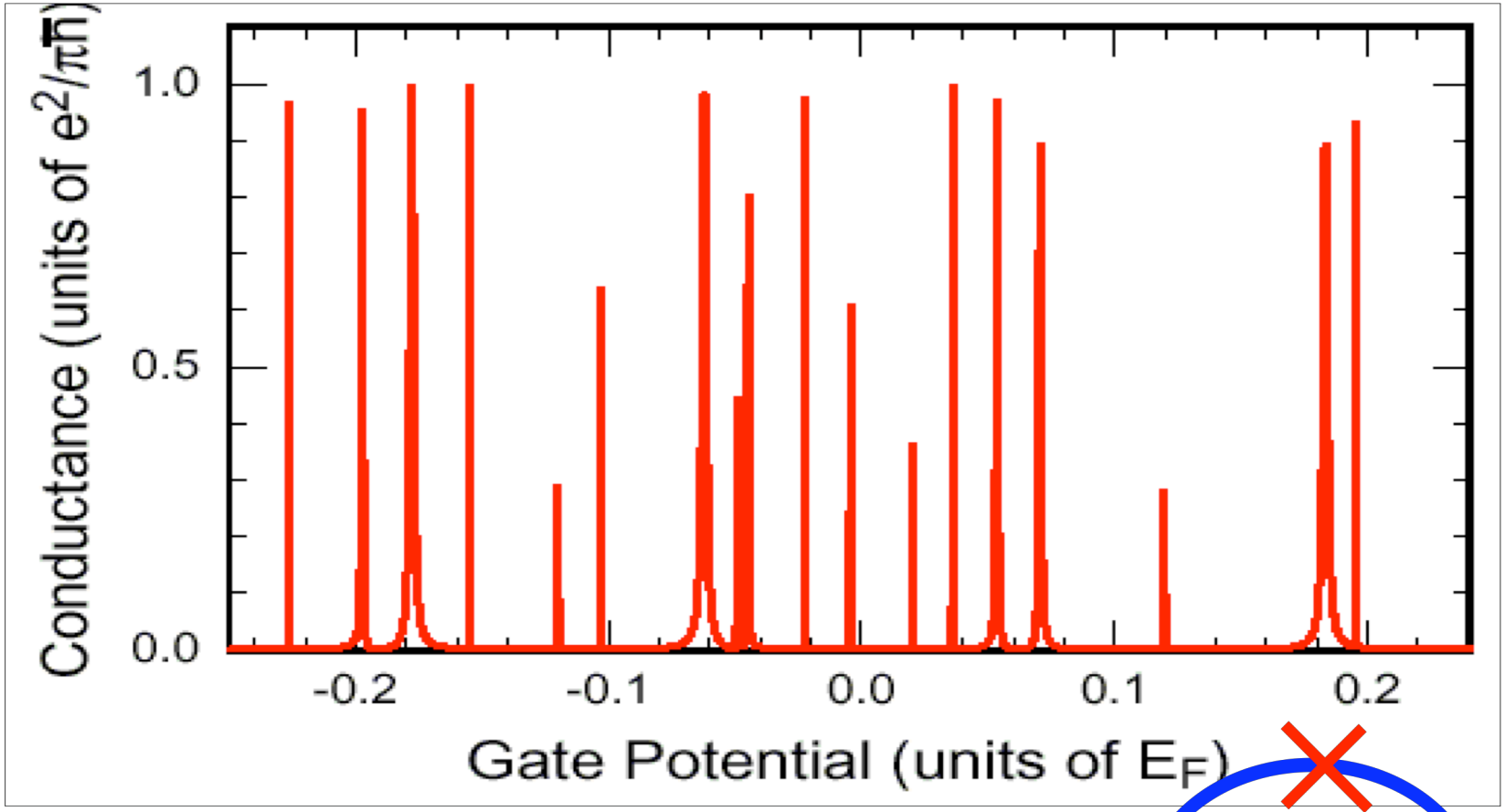
Asymmetry in sequence



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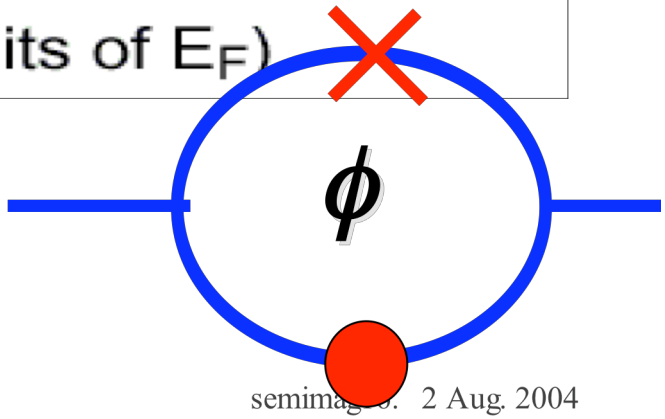

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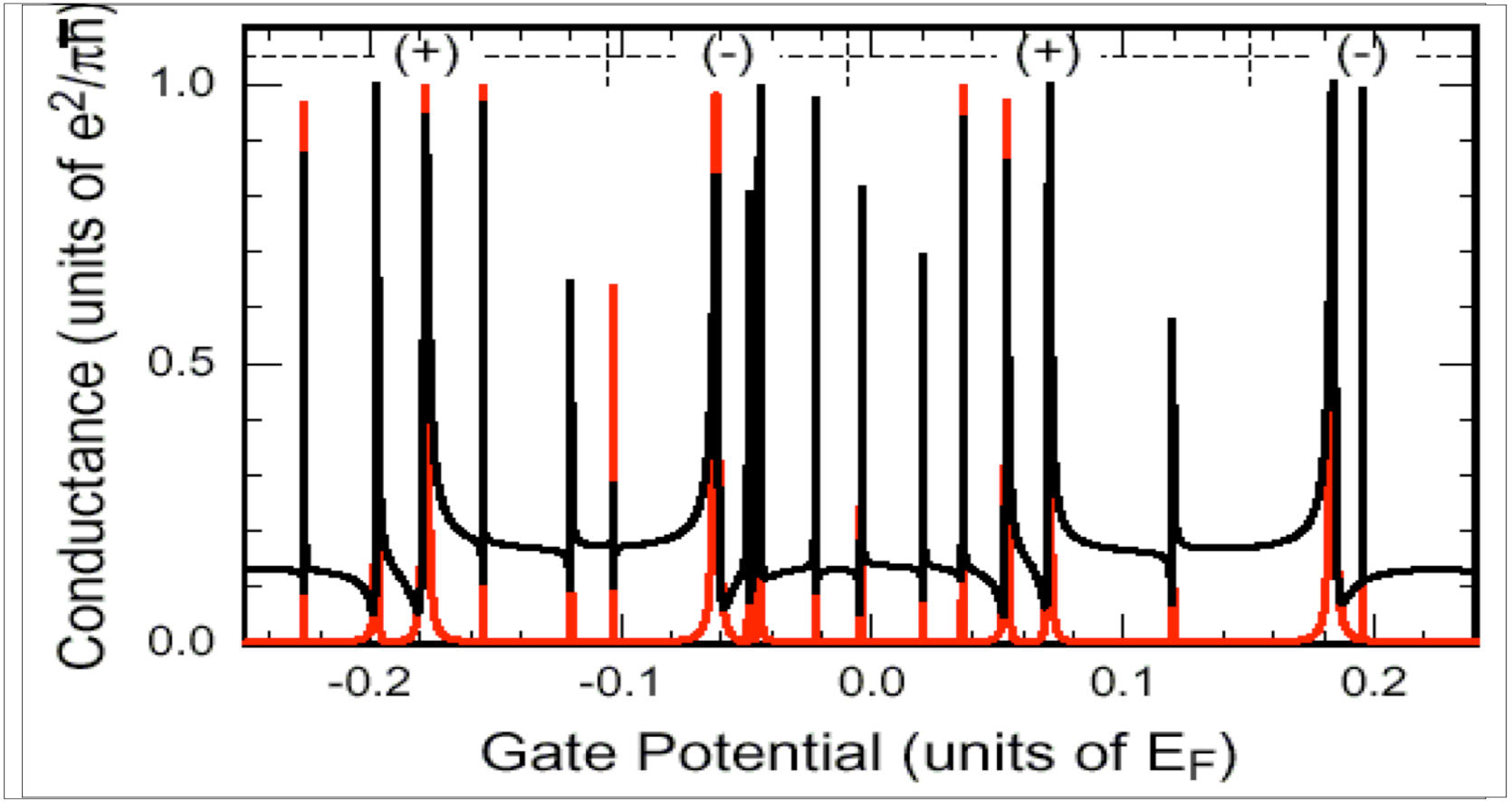
Asymmetry in sequence



- ——— AB ring
- ——— Pinched Off

$V_c = E_F$

$V_c = 2E_F$

- (+) q>0 dip in left
- (−) q<0 dip in right

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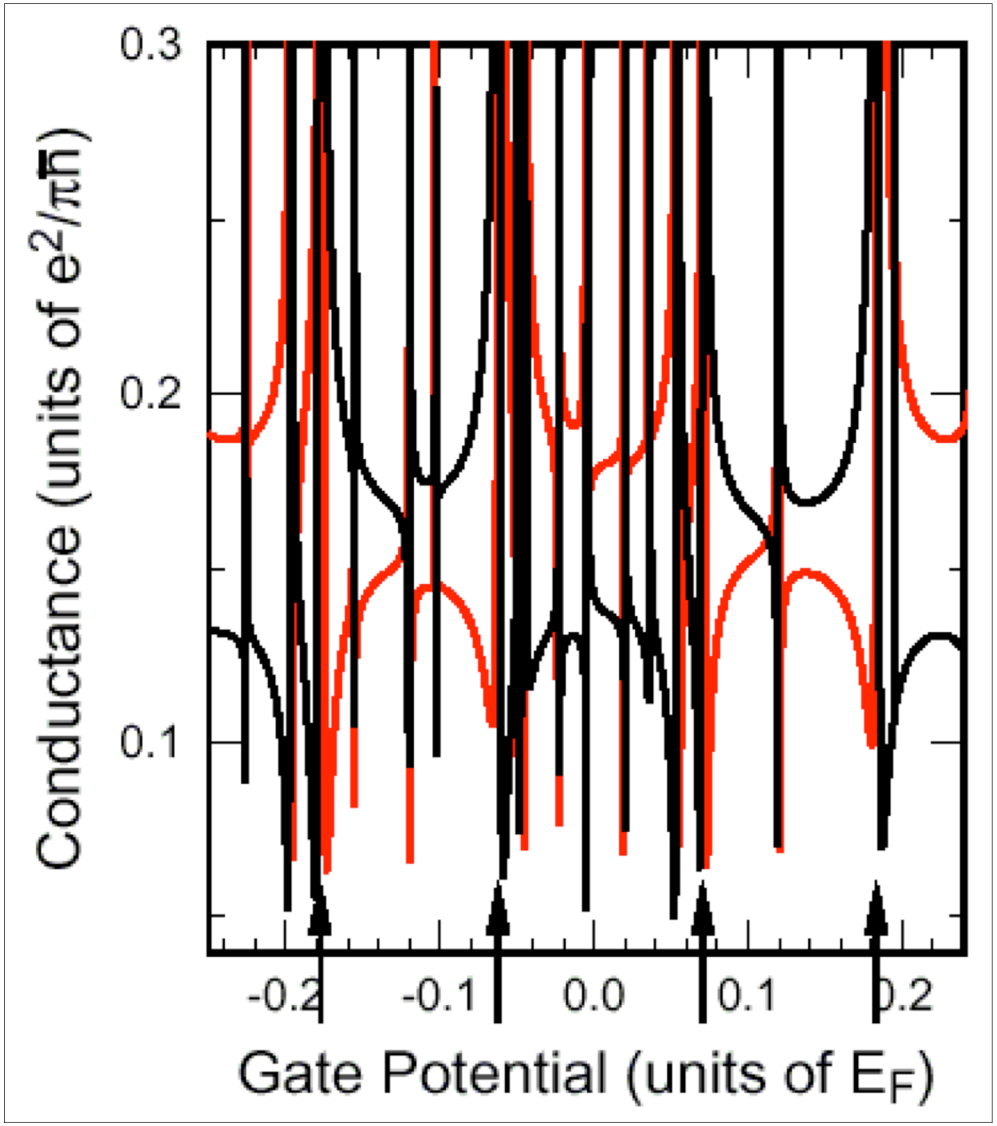
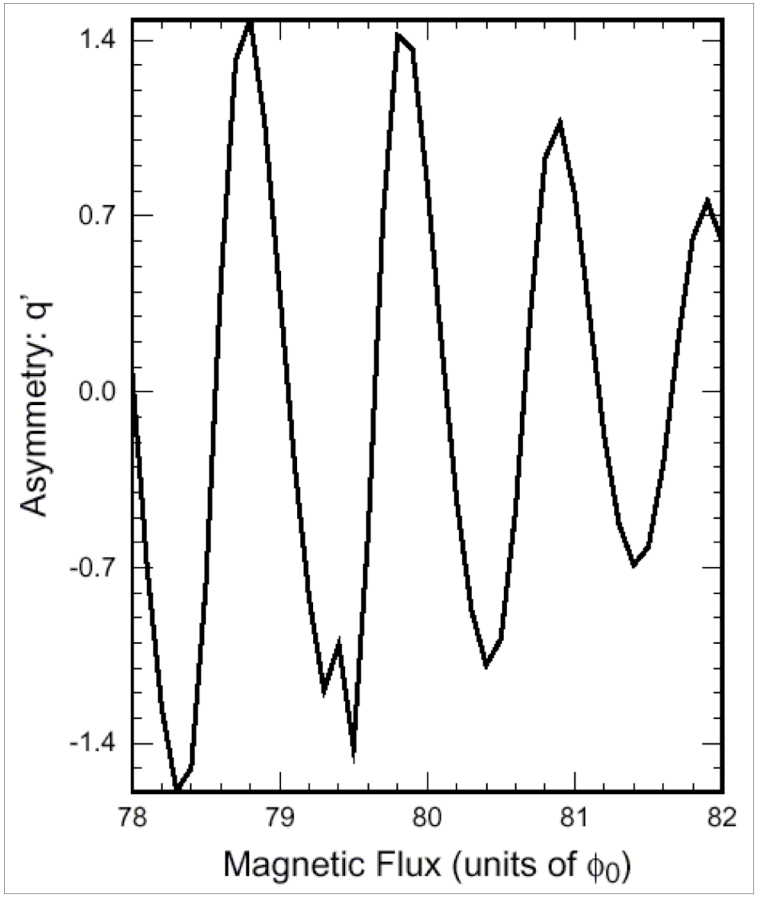
AB oscillation



$\phi/\phi_0 = 79.9$

$\phi/\phi_0 = 80.5$



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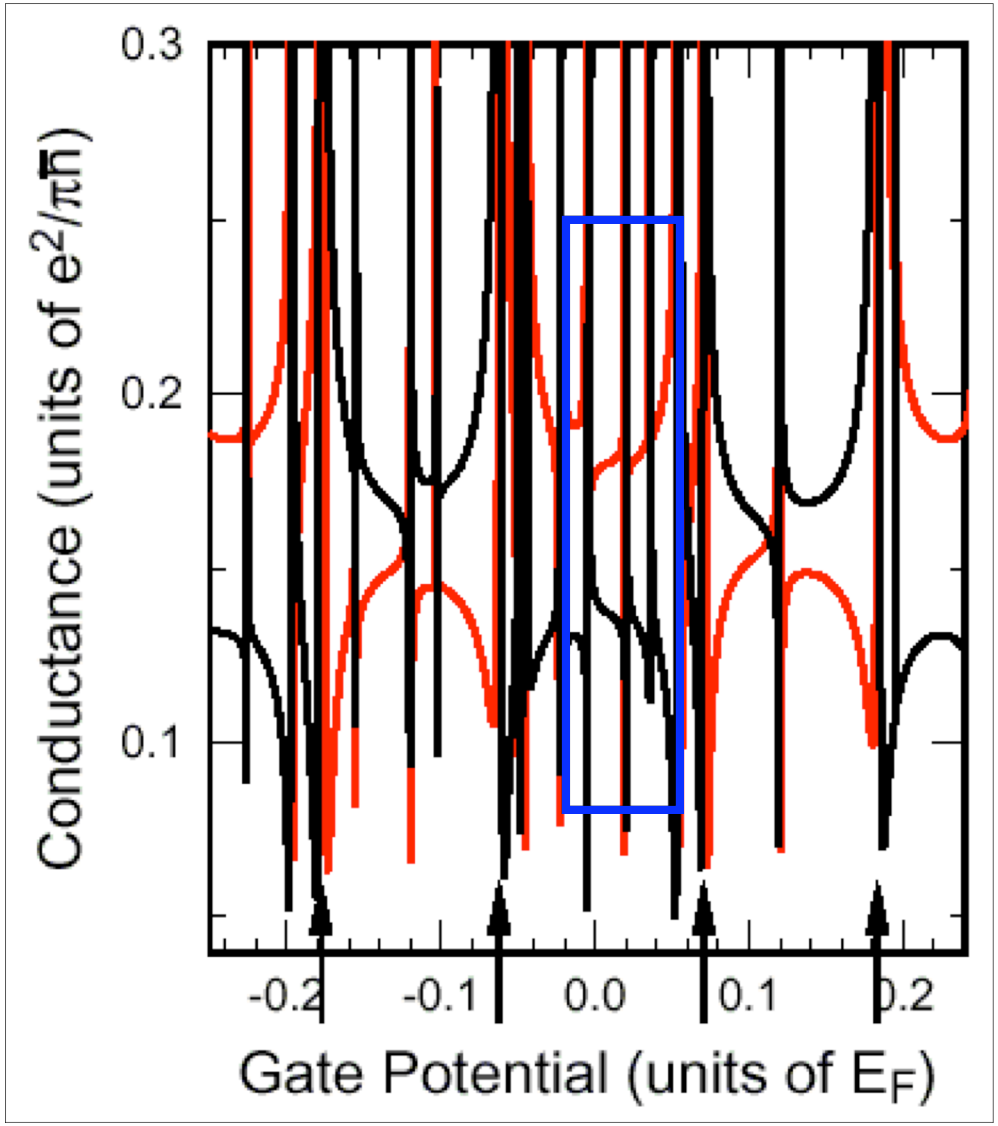
AB oscillation



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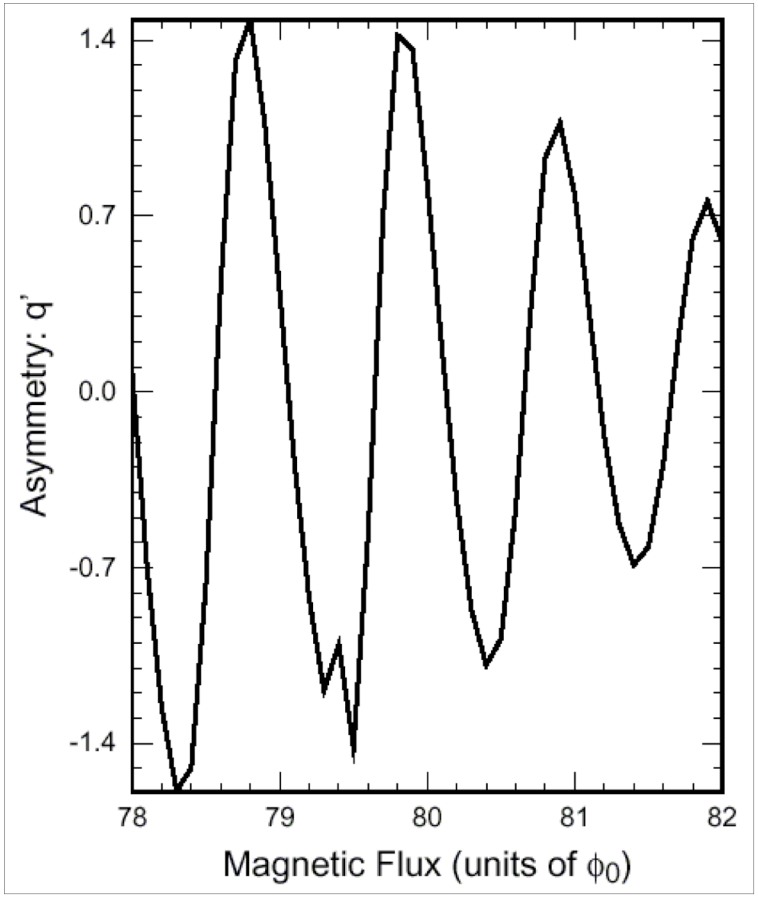
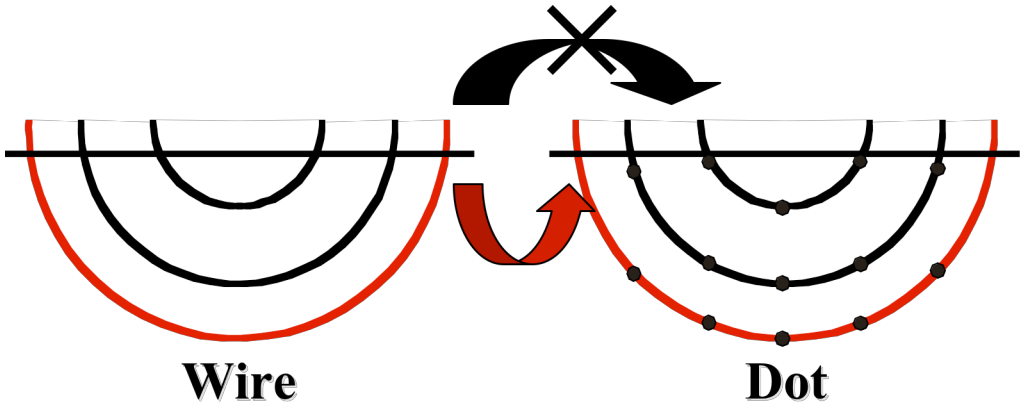
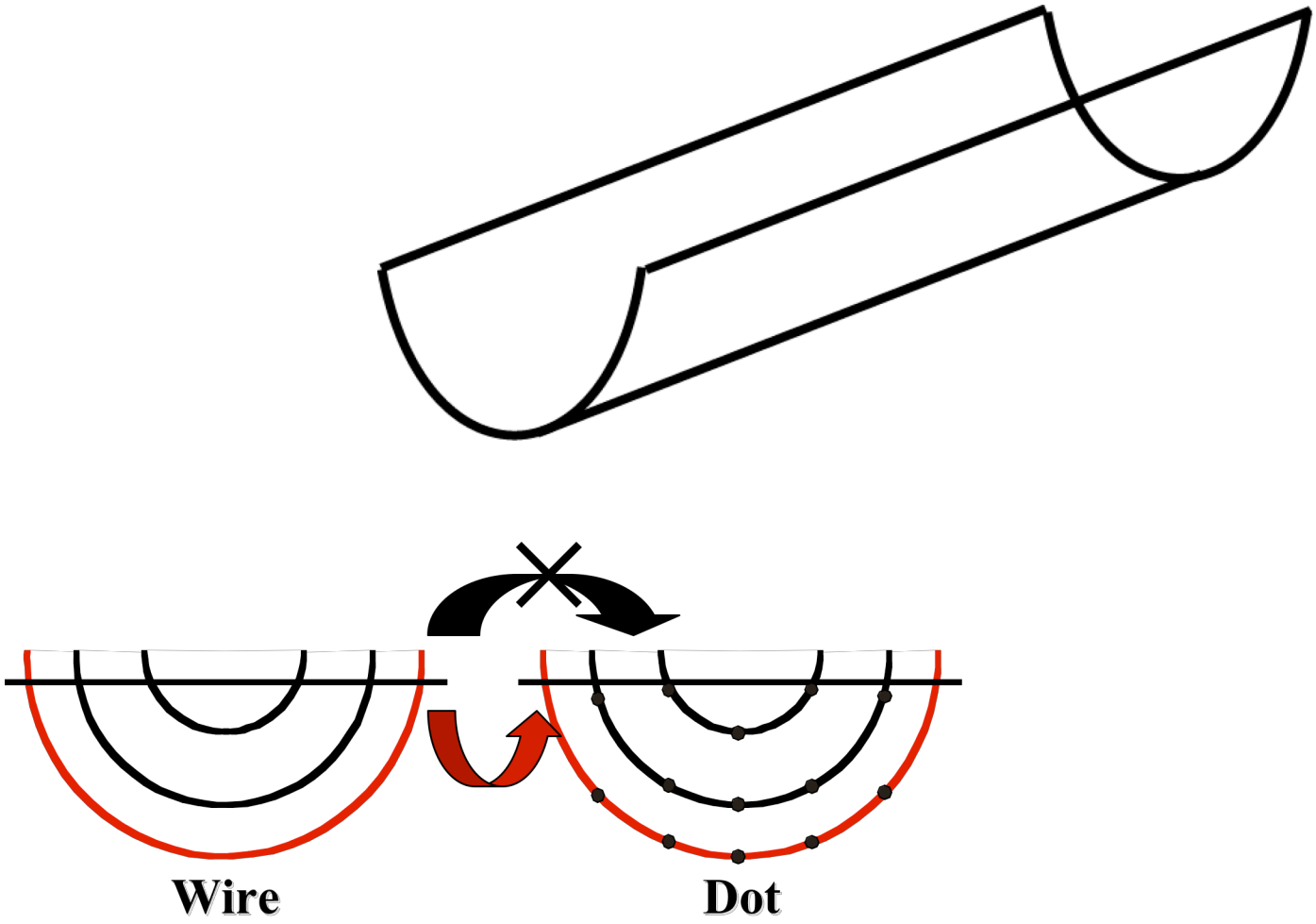


Broad and Narrow Peaks



Broad and Narrow Peaks



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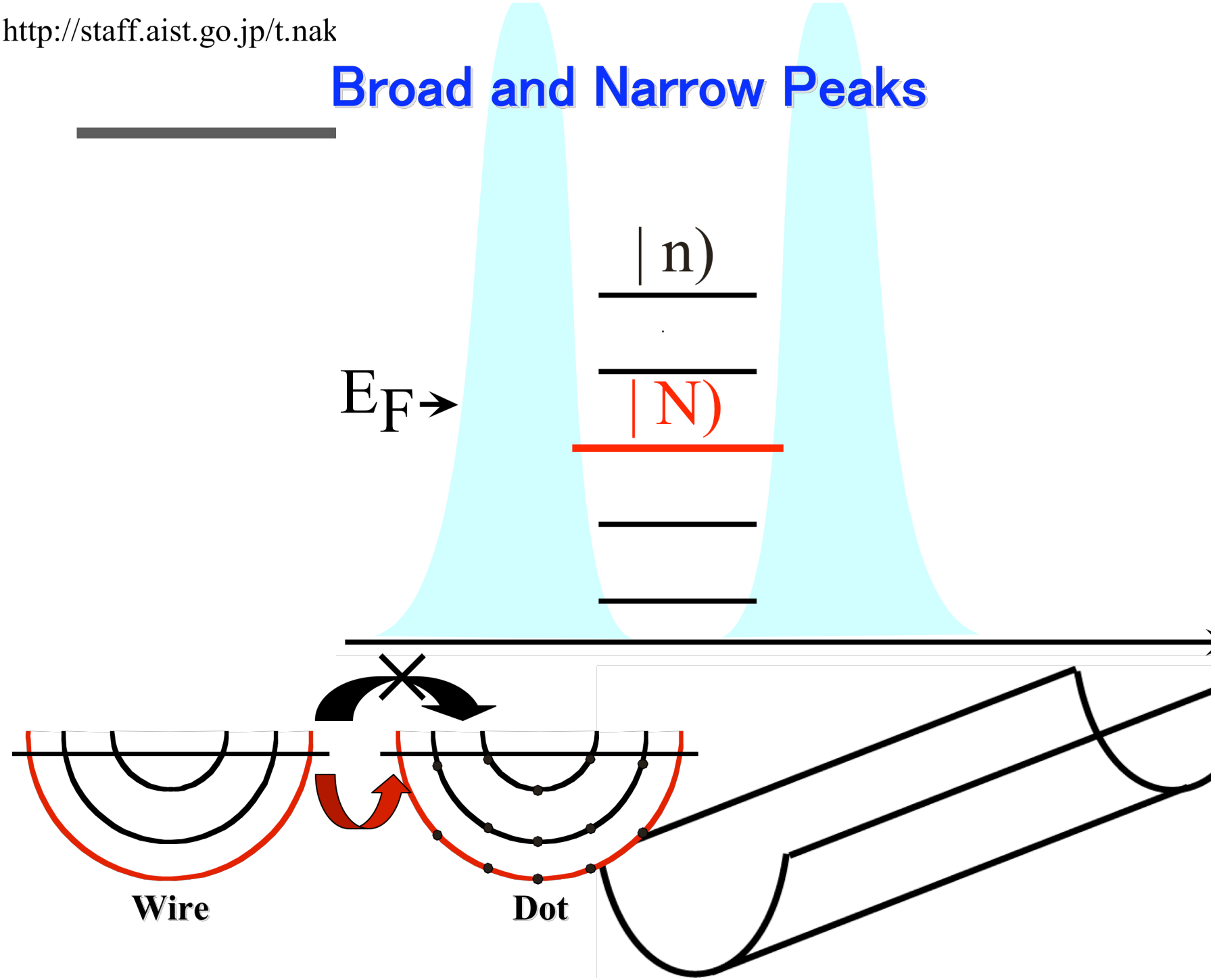
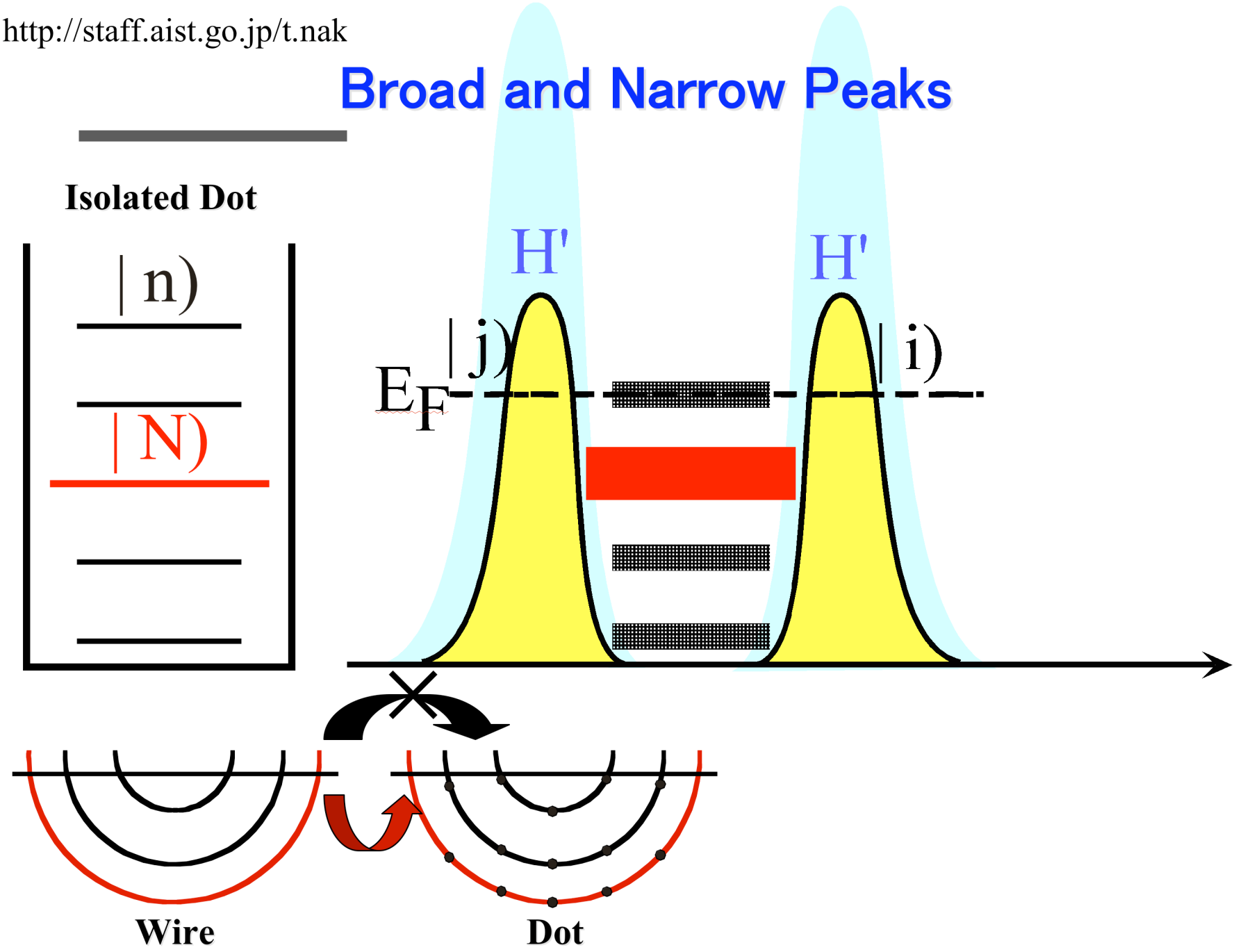
Broad and Narrow Peaks

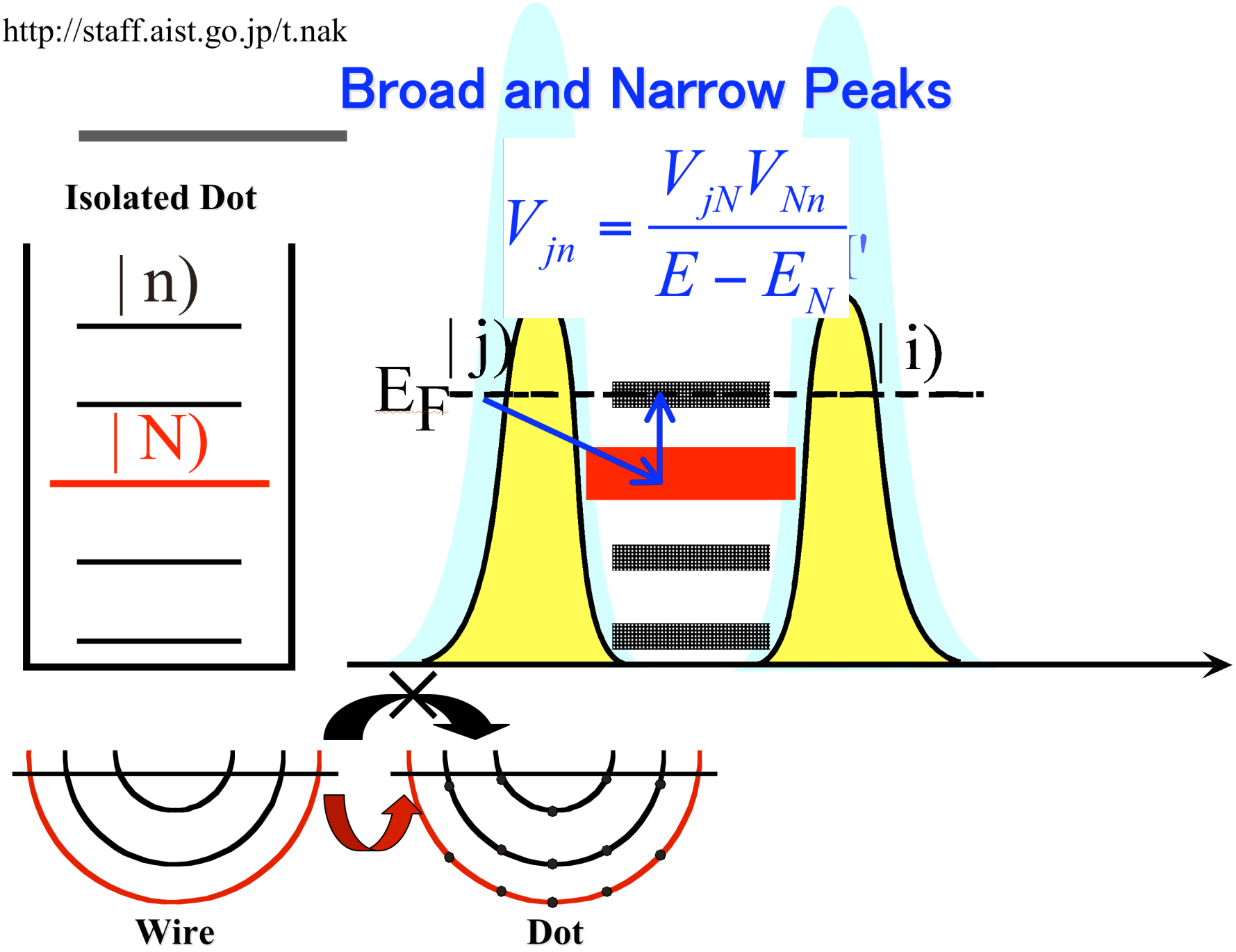


Broad and Narrow Peaks

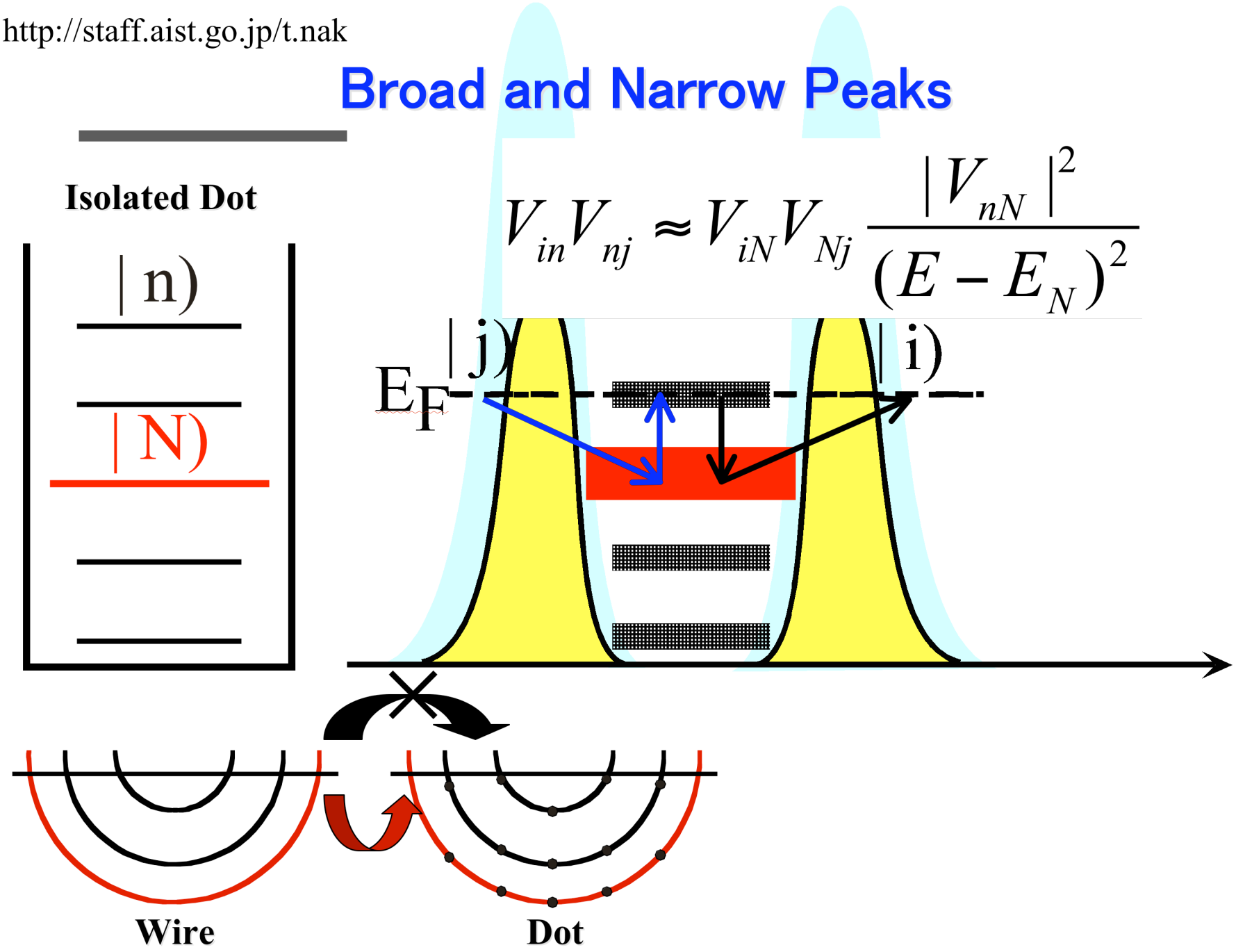


Broad and Narrow Peaks

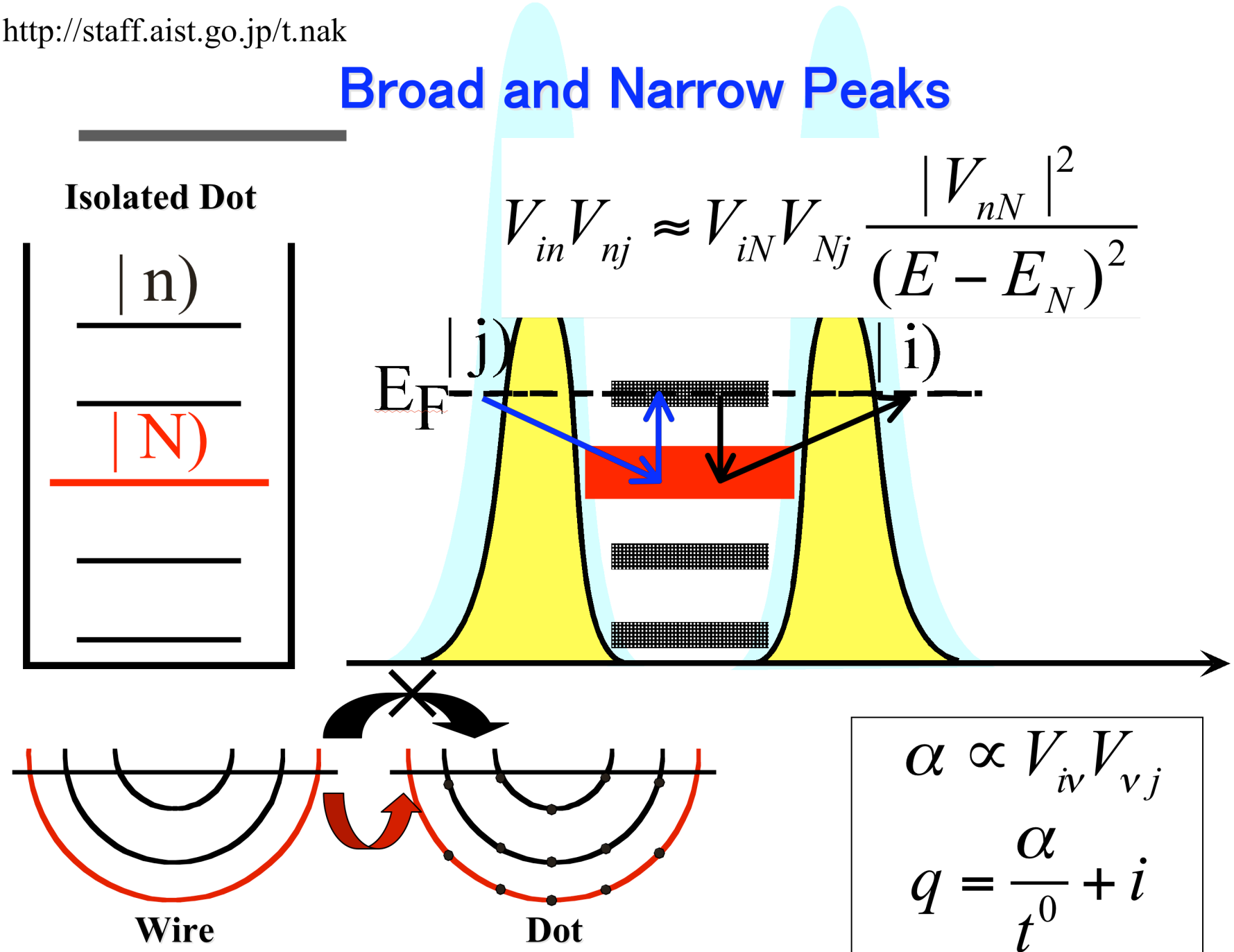
$$V_{jn} = \frac{V_{jN} V_{Nn}}{E - E_N}$$



Broad and Narrow Peaks



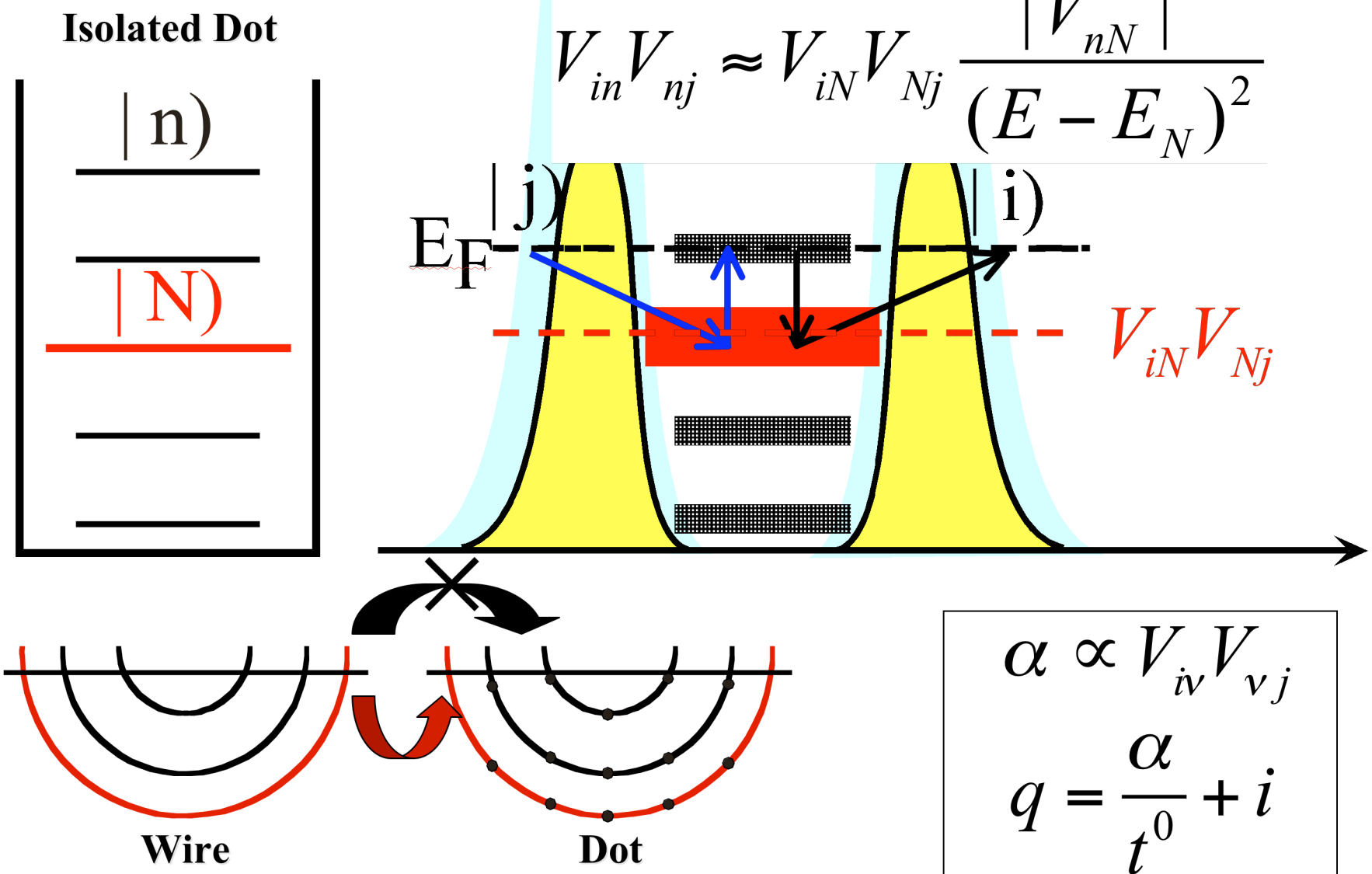
Broad and Narrow Peaks



$$\alpha \propto V_{iv}V_{vj}$$

$$q = \frac{\alpha}{t^0} + i$$

Broad and Narrow Peaks



$$\alpha \propto V_{iv}V_{vj}$$

$$q = \frac{\alpha}{t^0} + i$$

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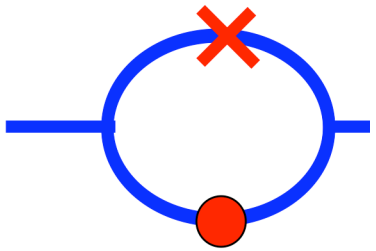
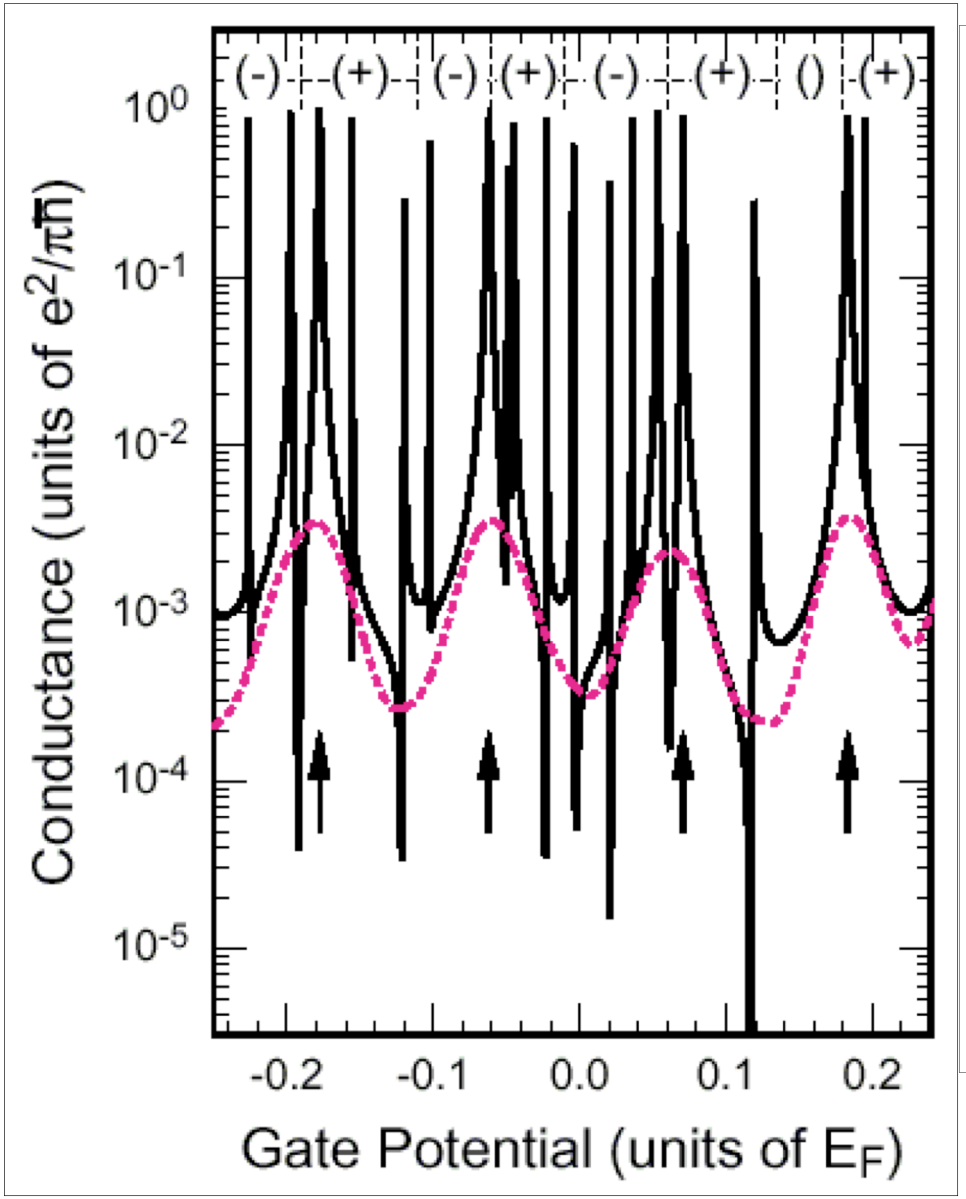
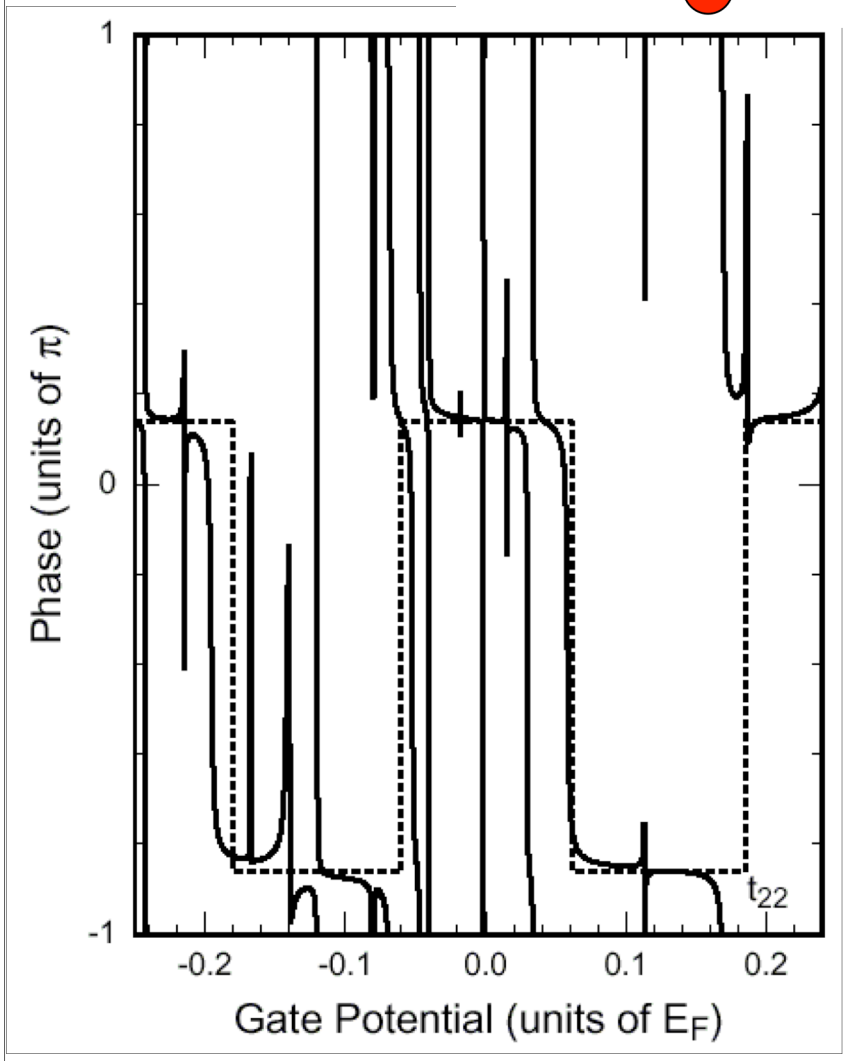
Control Gate is Pinched Off





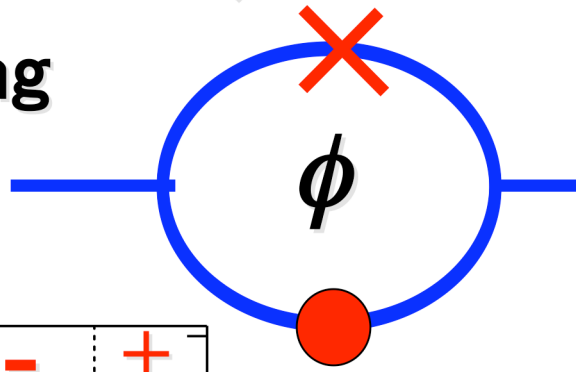


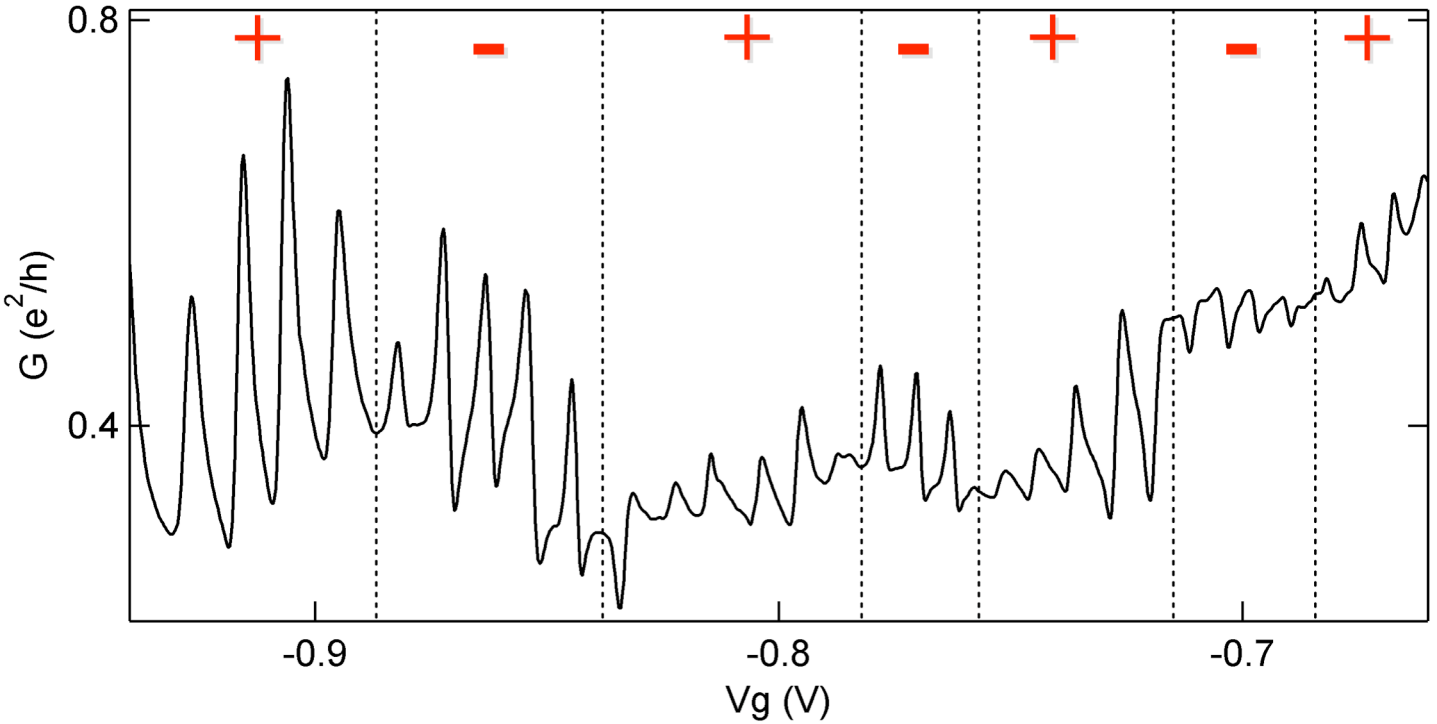
Continuum: | N>

Experiment

(H. Aikawa *et al.* cond-mat/0312431)

A Quantum Dot without AB ring





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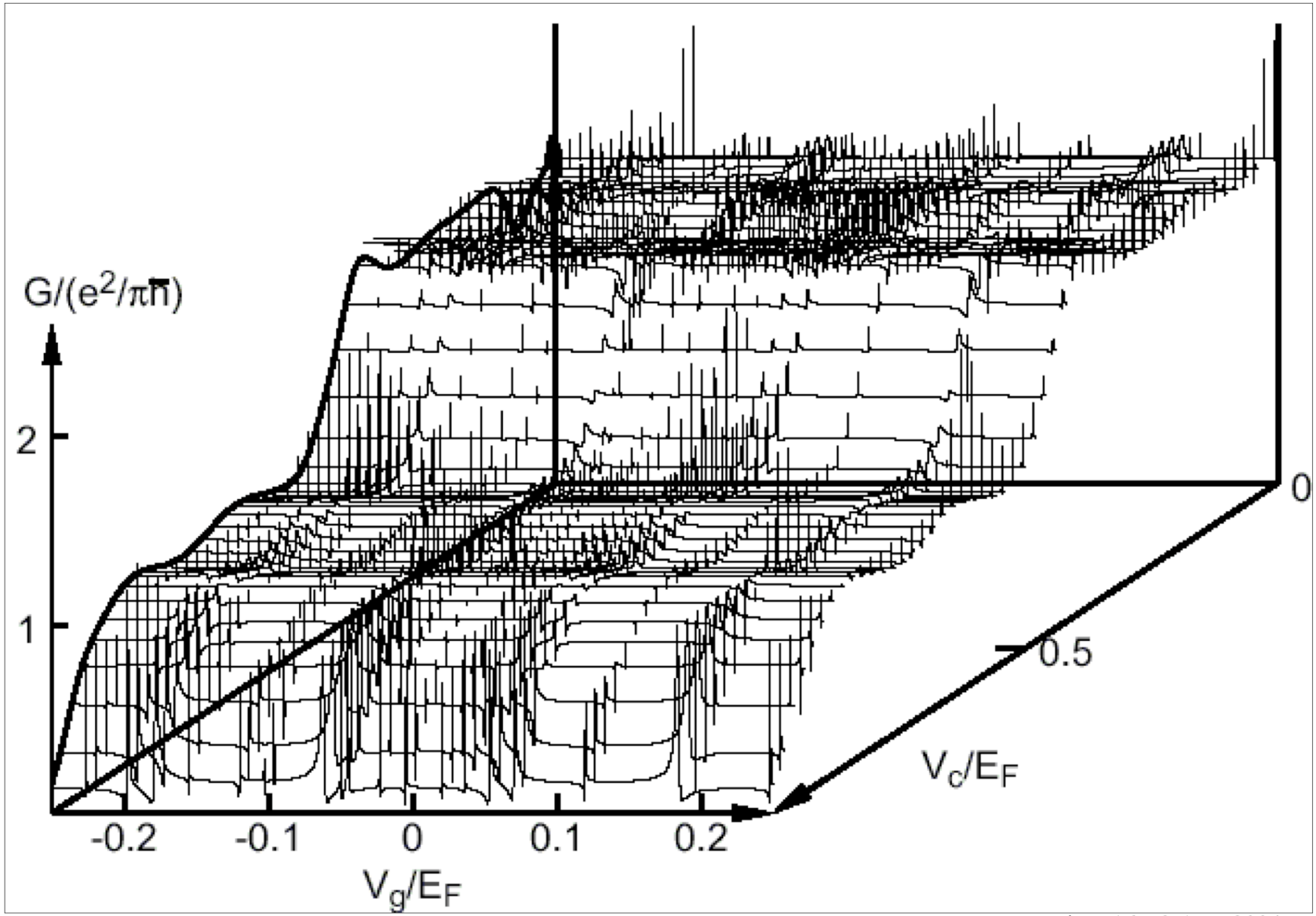
Control gate (Several channels)



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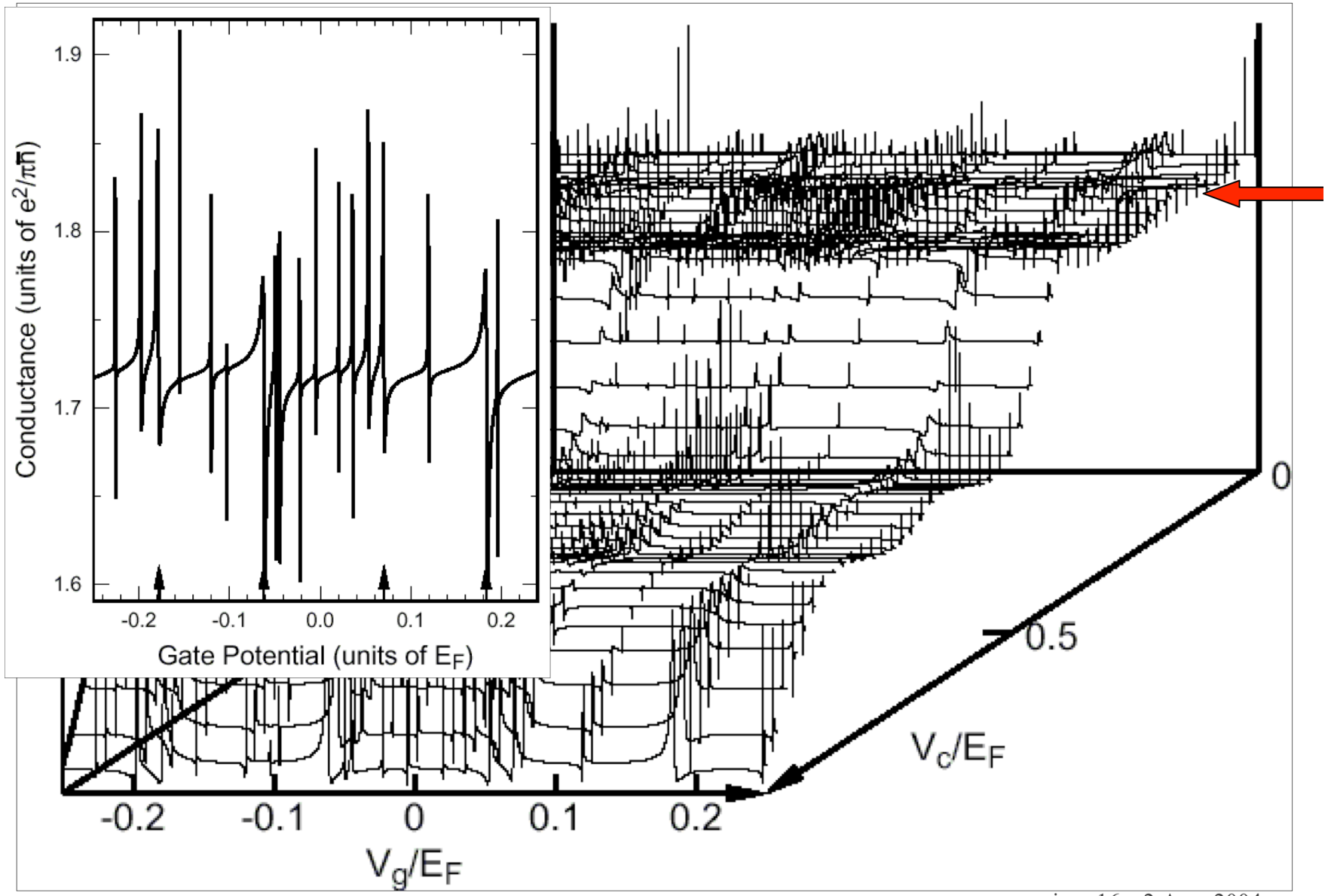
Control gate (Several channels)



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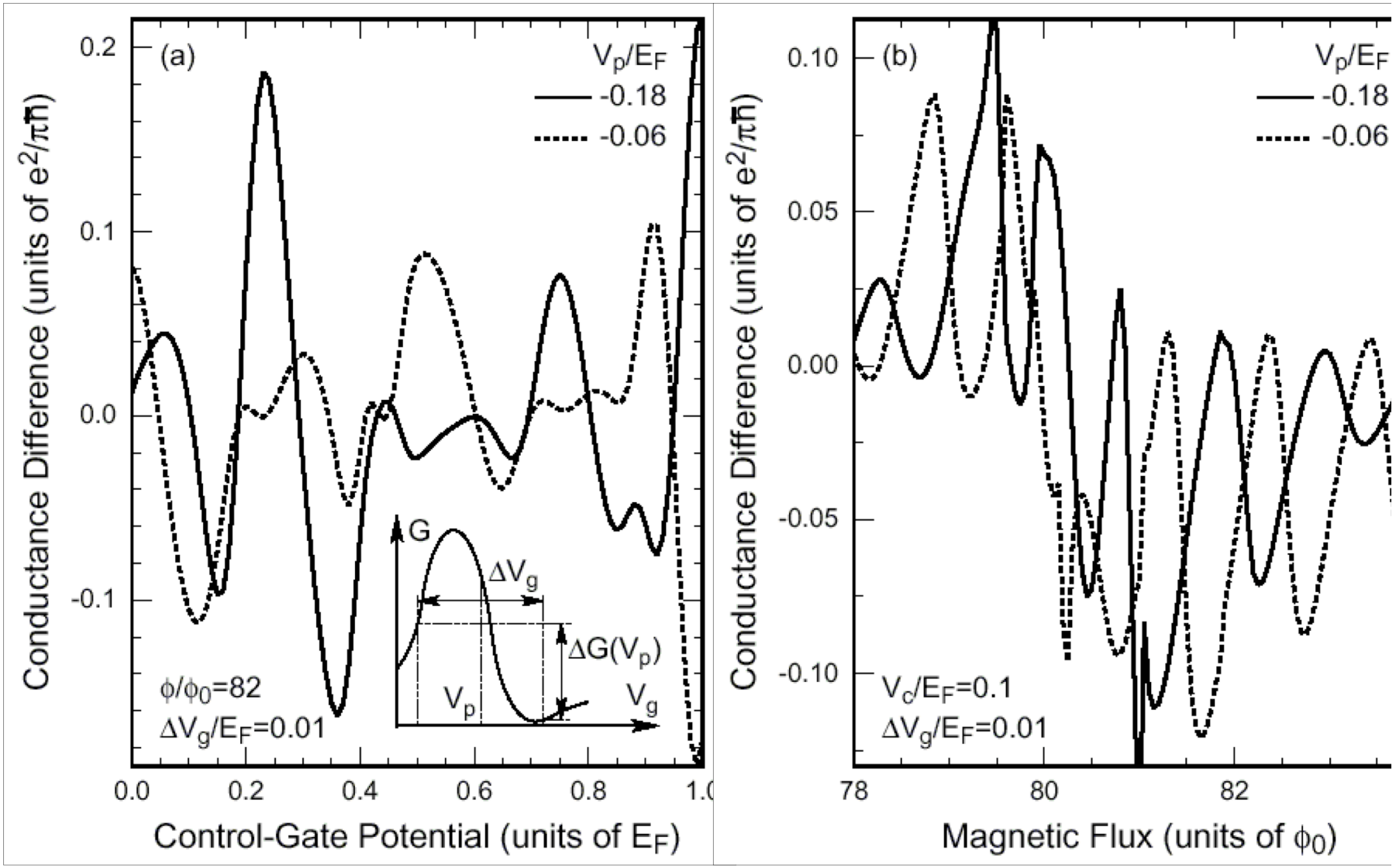
Asymmetry q



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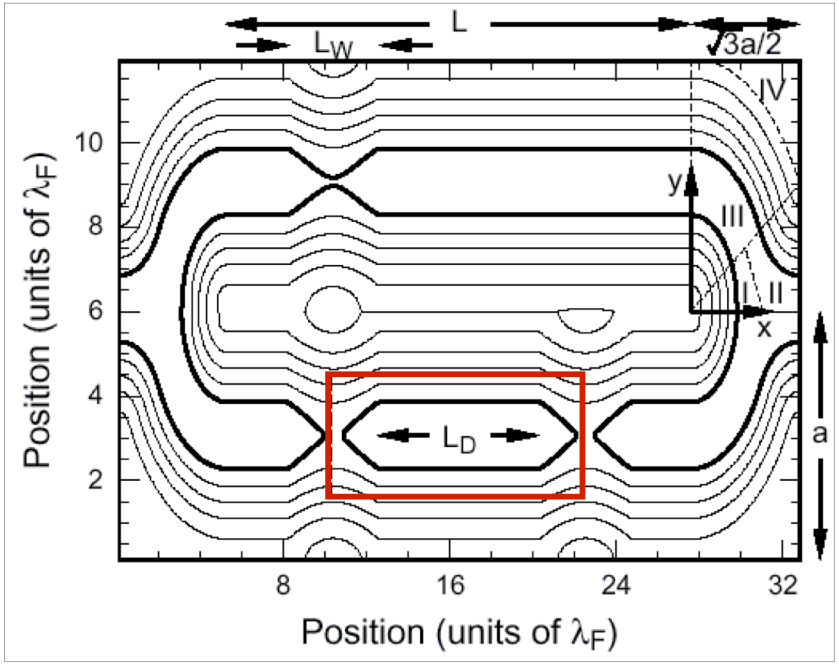
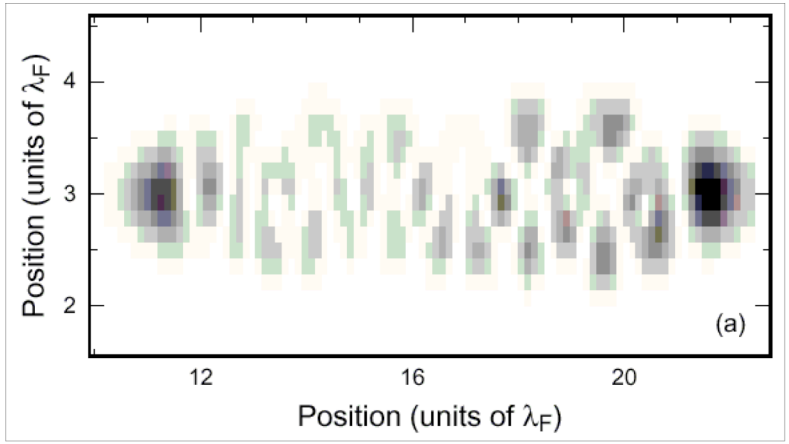
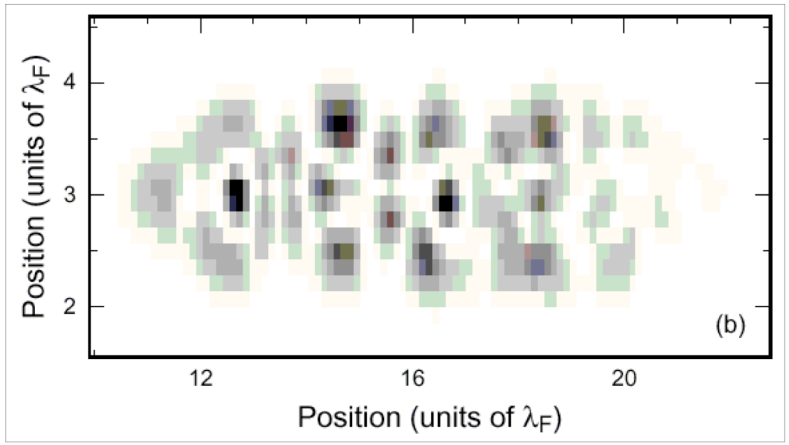
Wave Functions







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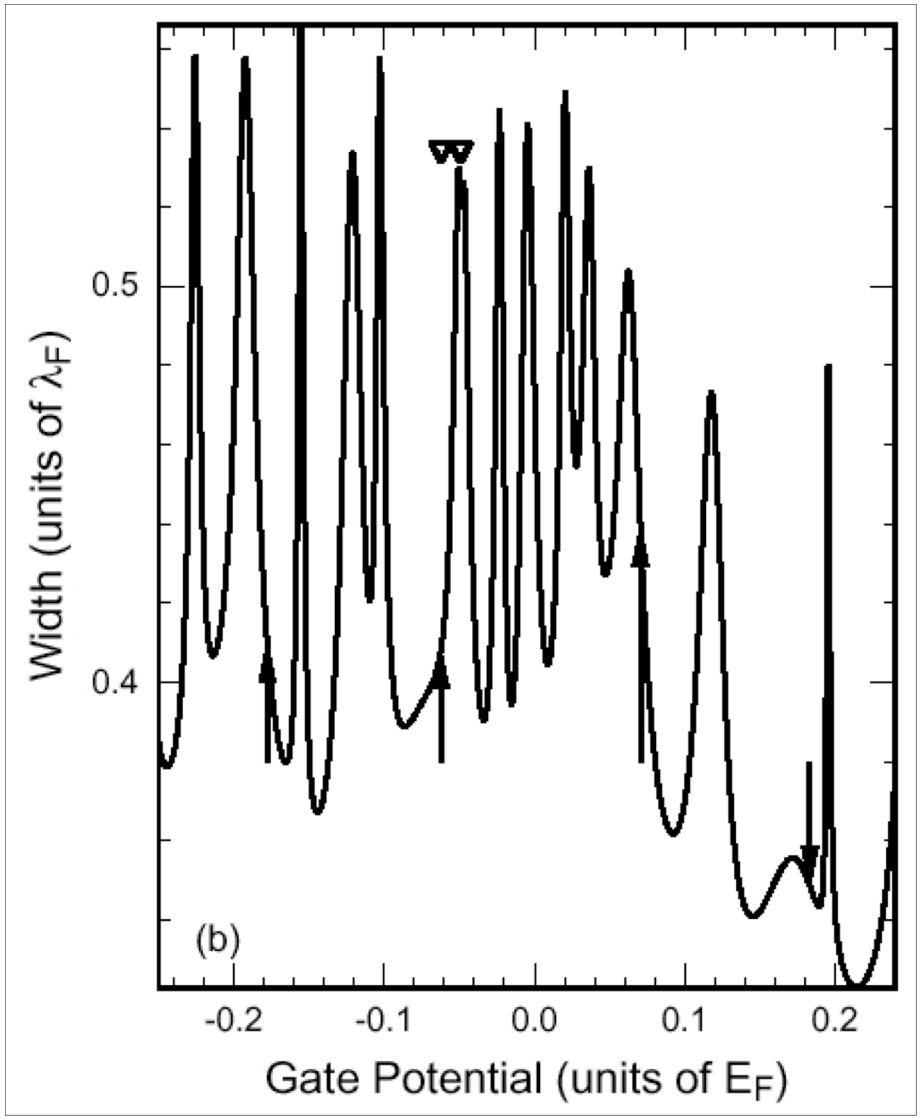
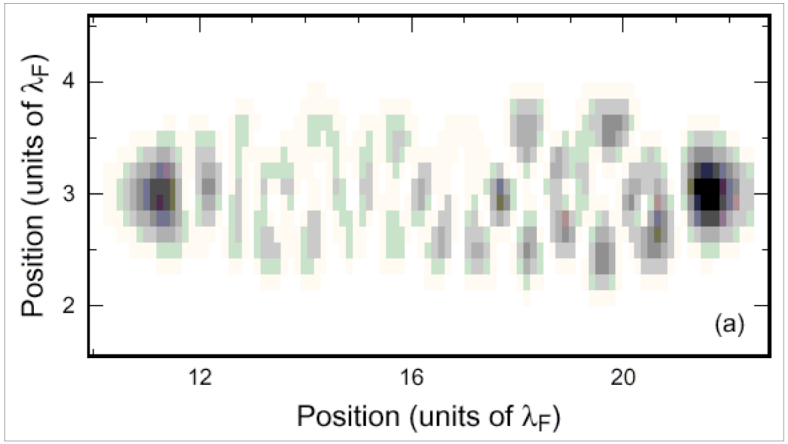
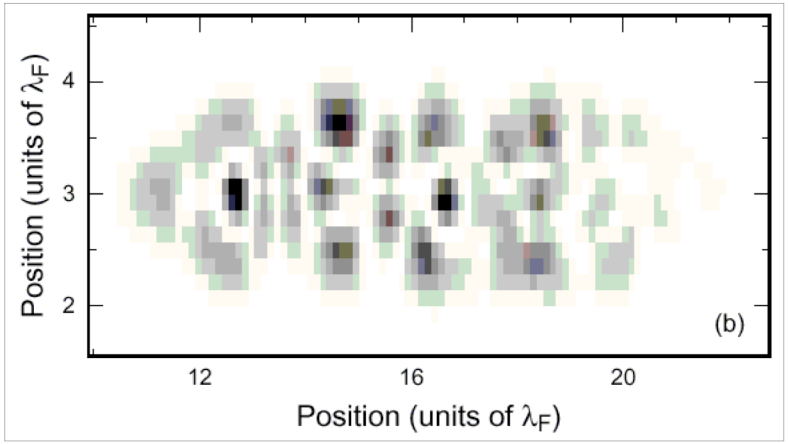
Wave Functions

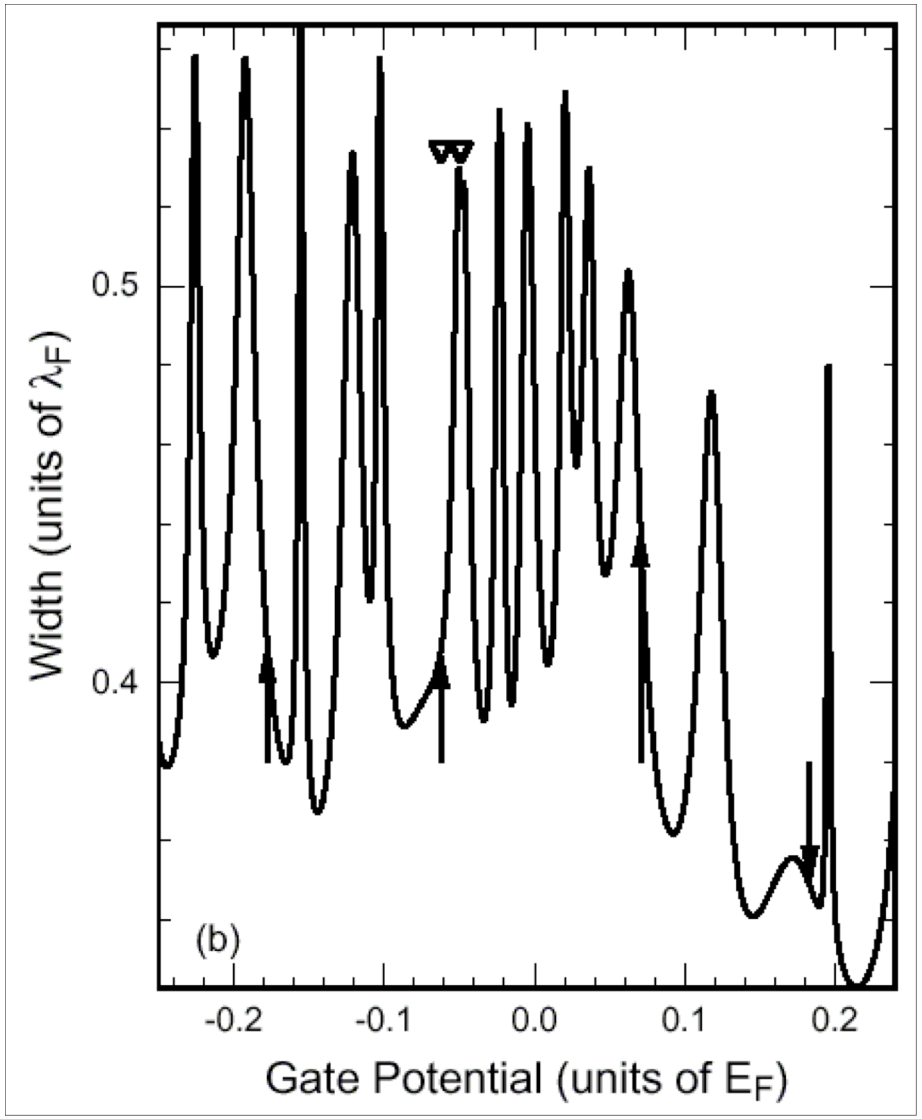


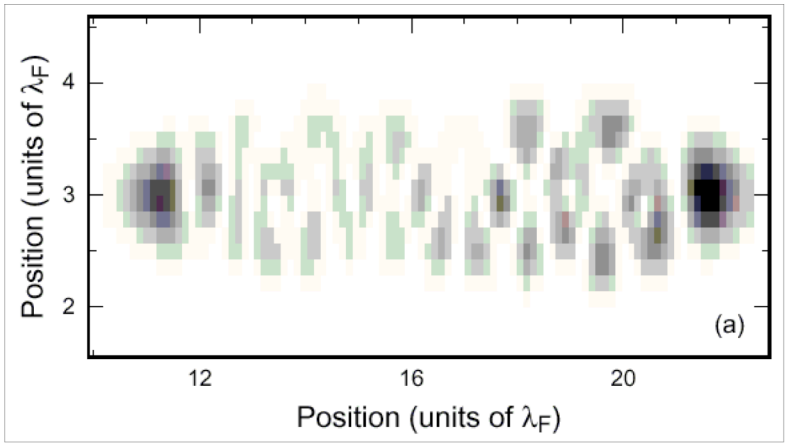


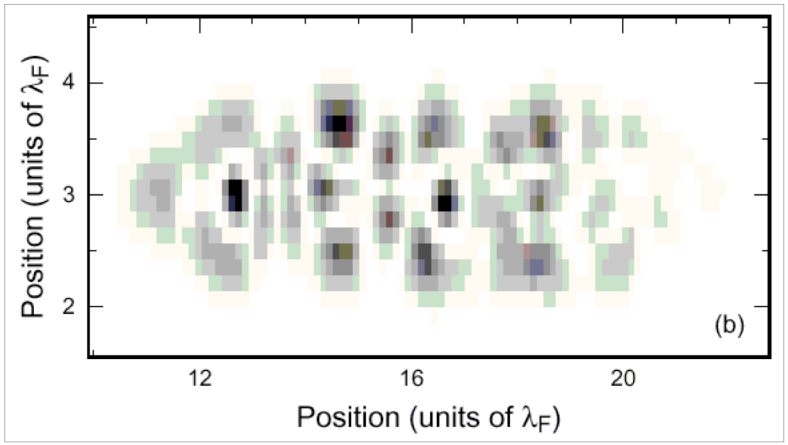


http://staff.aist.go.jp/t.nakanishi/

Wave Functions







$$\Delta y = \sqrt{\left\langle (y - \langle y \rangle)^2 \right\rangle}$$

Conclusion

- We have shown
  - Sequence of Fano line-shape with similar asymmetry and
  - Phase persistence in AB effect,

which qualitatively explains the experiment.

- Strongly and Weekly coupled levels
- The continuum in Fano effect is state in
  - opposite arm to QD in AB ring
  - strongly coupled level in QD
- TN, Terakura, Ando, PRB 69, 115307 (2004)