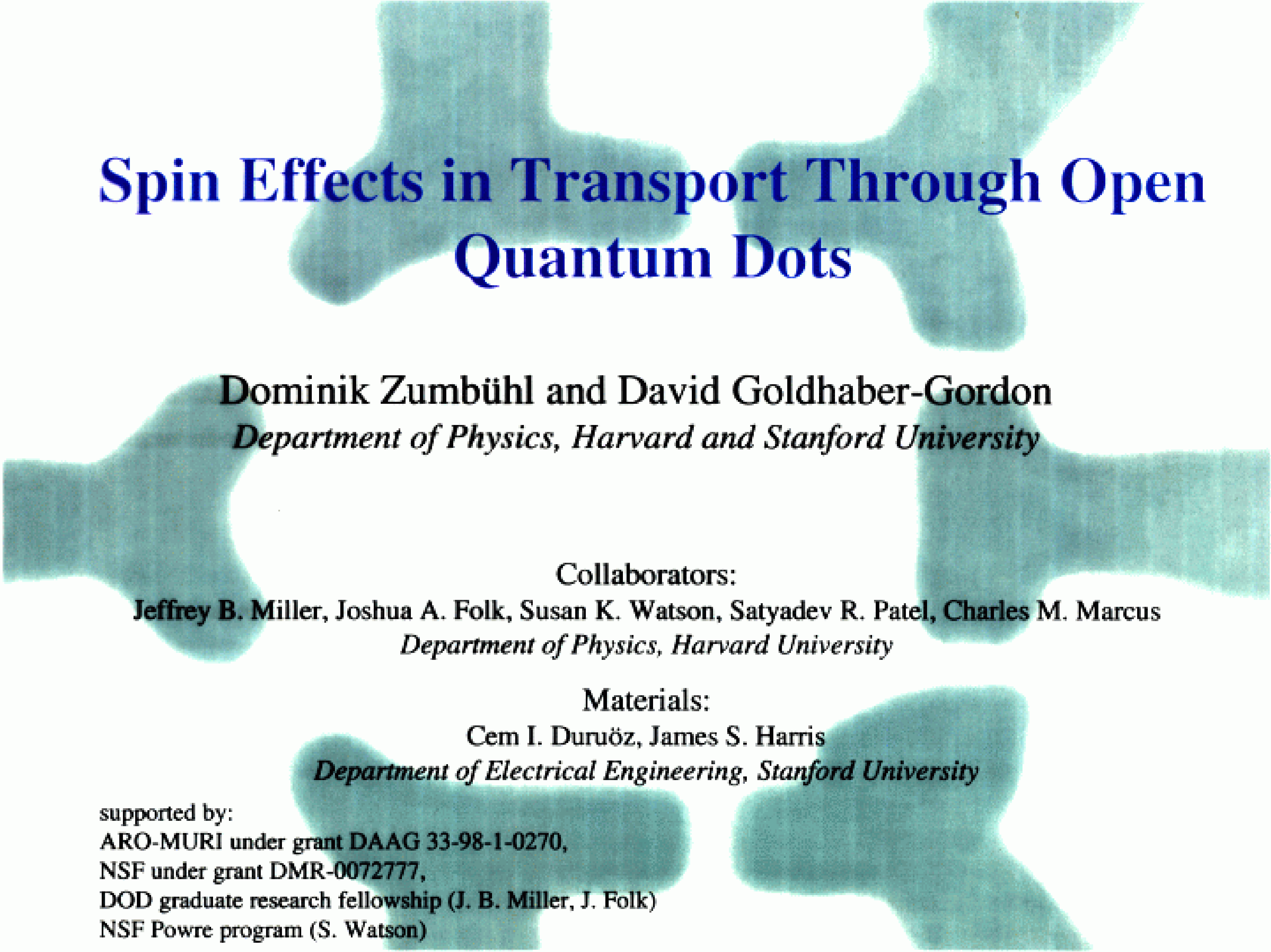

Spin Effects in Transport Through Open Quantum Dots

Dominik Zumbühl and David Goldhaber-Gordon
Department of Physics, Harvard and Stanford University

Collaborators:
Jeffrey B. Miller, Joshua A. Folk, Susan K. Watson, Satyadev R. Patel, Charles M. Marcus
Department of Physics, Harvard University

Materials:
Cem I. Duruöz, James S. Harris
Department of Electrical Engineering, Stanford University

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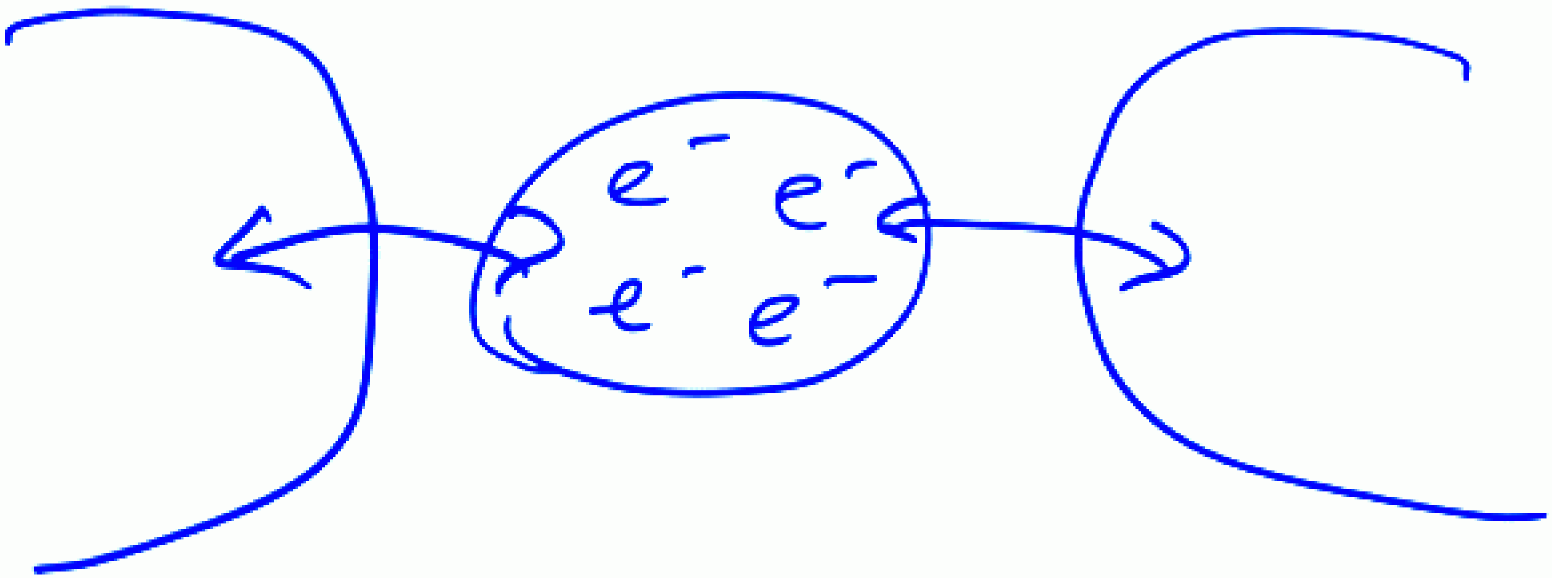
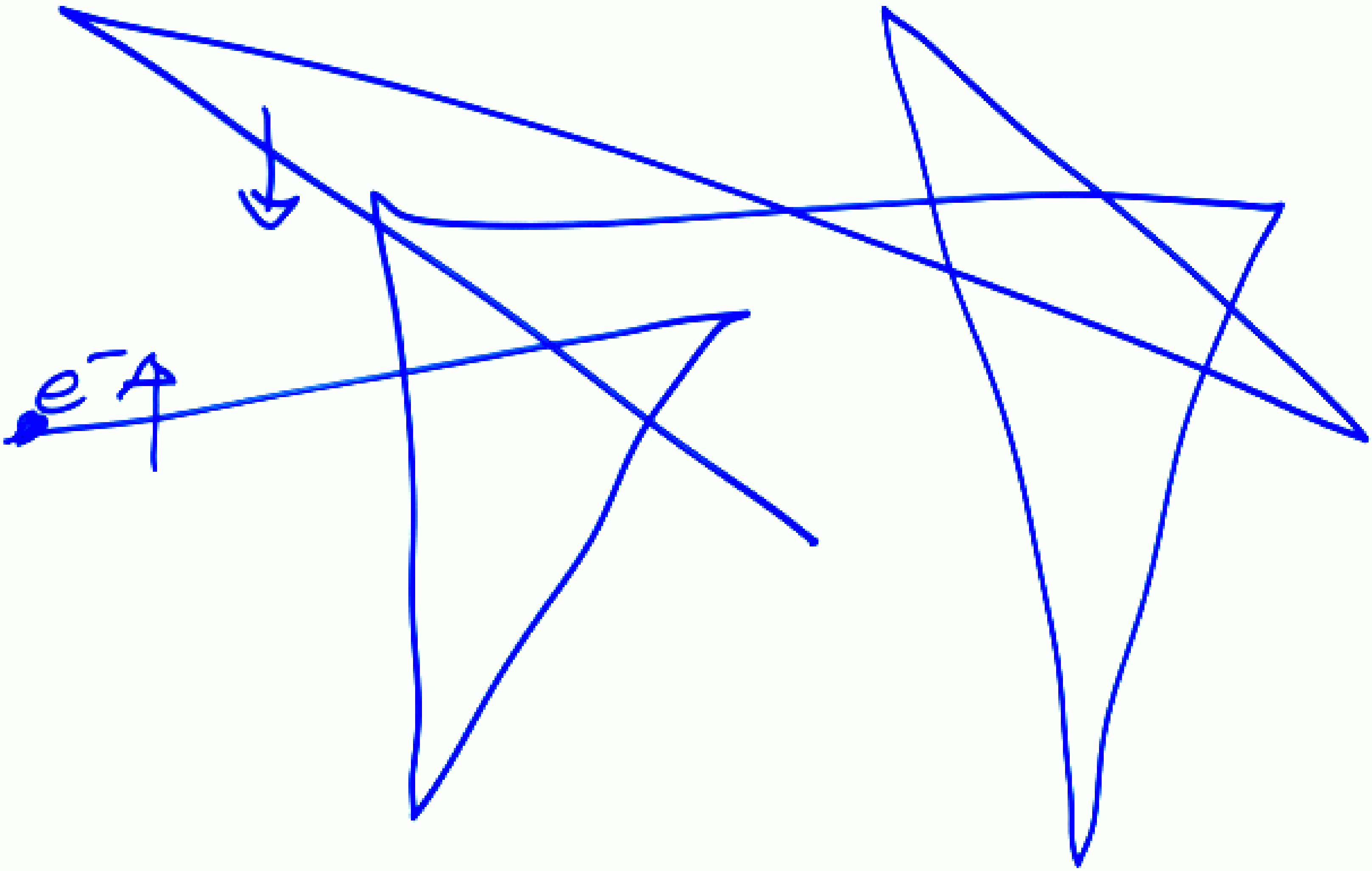
Introduction

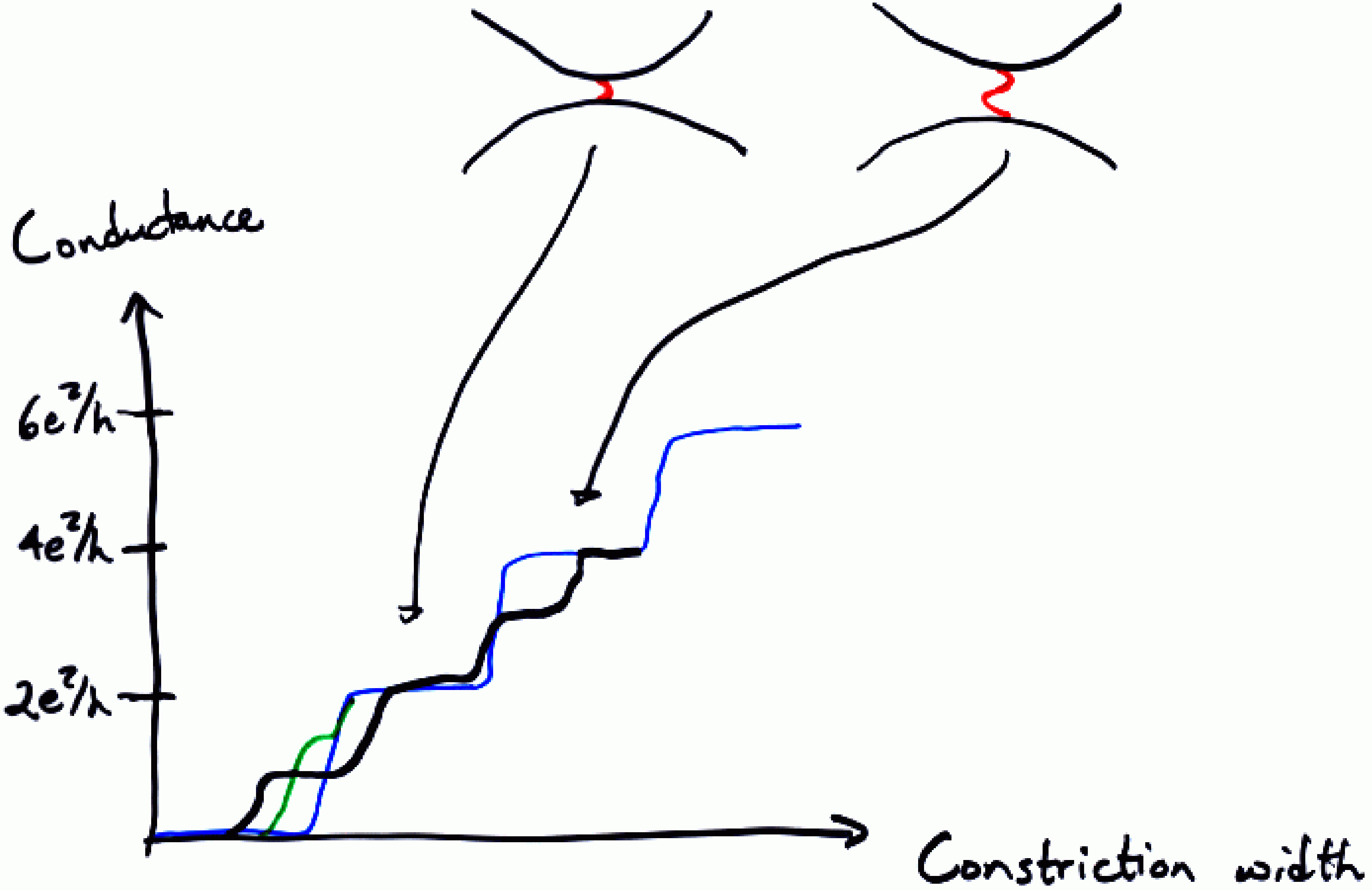
- quantum dot or "artificial atom": a few electrons confined to a small region in space
- electrons in small structures behave differently from those in bulk materials
    - quantized energy levels
    - electron-electron interactions



Electron spin: transport and relaxation

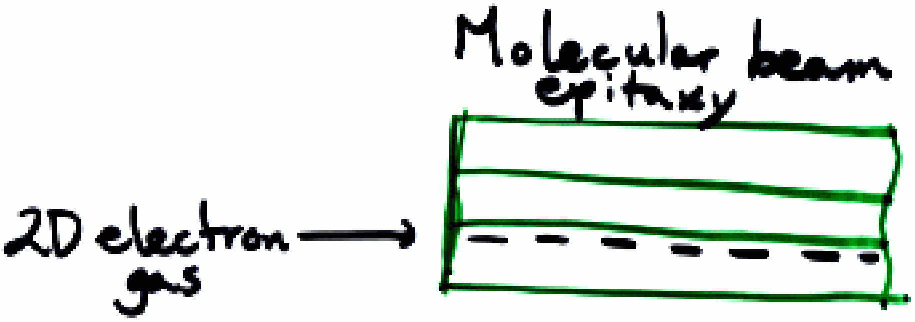


Quantized transport through a point contact



Technology

- techniques of semiconductor chip-making are borrowed to make our structures --- features even smaller than on Pentium IV!
    - electron-beam lithography
    - metal evaporation
    - etching



- special refrigerator cools electrons to a third of a degree above absolute zero, so that kT < important energies of the system
    - coolant is ^{3}He rather than freon
- current amplifiers measure currents as small as femtoamps (10^{-15} amp)

Introduction

- we've developed a new technique to investigate spin relaxation in a GaAs quantum dot
- obtain spin information by performing a (charge) transport measurement
- measure spin relaxation time τ_{spin} in GaAs two-dimensional electron gases (2DEGs)

Applications

- use this technique to study "0.7 structure"
- spin orbit physics in 2DEGs

Method to Investigate Spin Physics

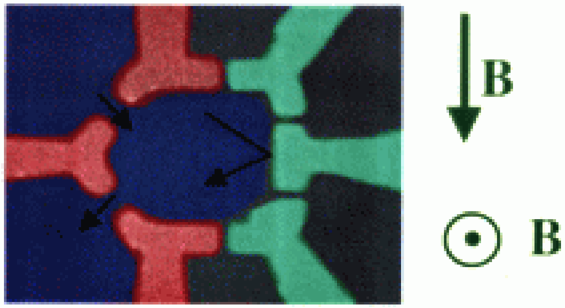
compare transport through
LARGE (100 μm x 100 μm) vs **SMALL** (1 μm x 1 μm) dot

large in-plane B-field ($g\mu_B B \geq kT$): spin-resolved plateaux

small perpendicular B-field: breaks time-reversal symmetry

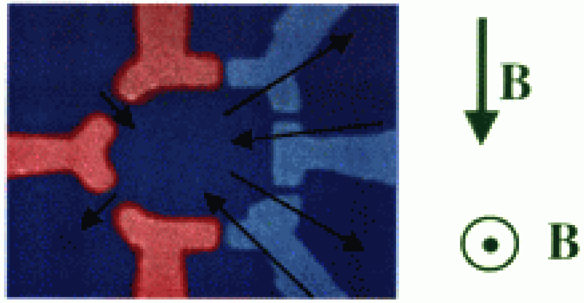
OPEN dot: $g_{lead} > e^2/h$

SMALL dot:
enclosed by gates



$\tau_{dwell} = 0.3\text{ns}$

LARGE dot:
not enclosed by gates

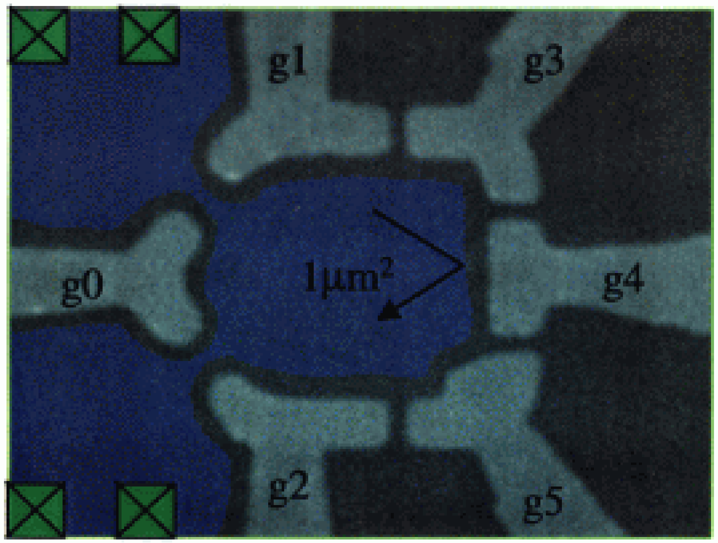


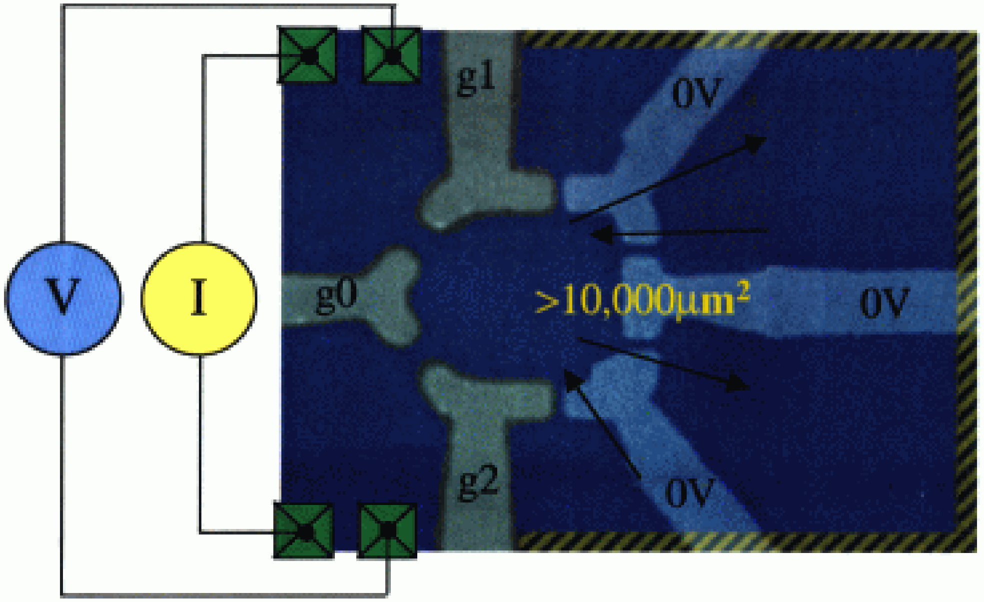
$\tau_{dwell} = 3\ \mu\text{s}$

Device Parameters

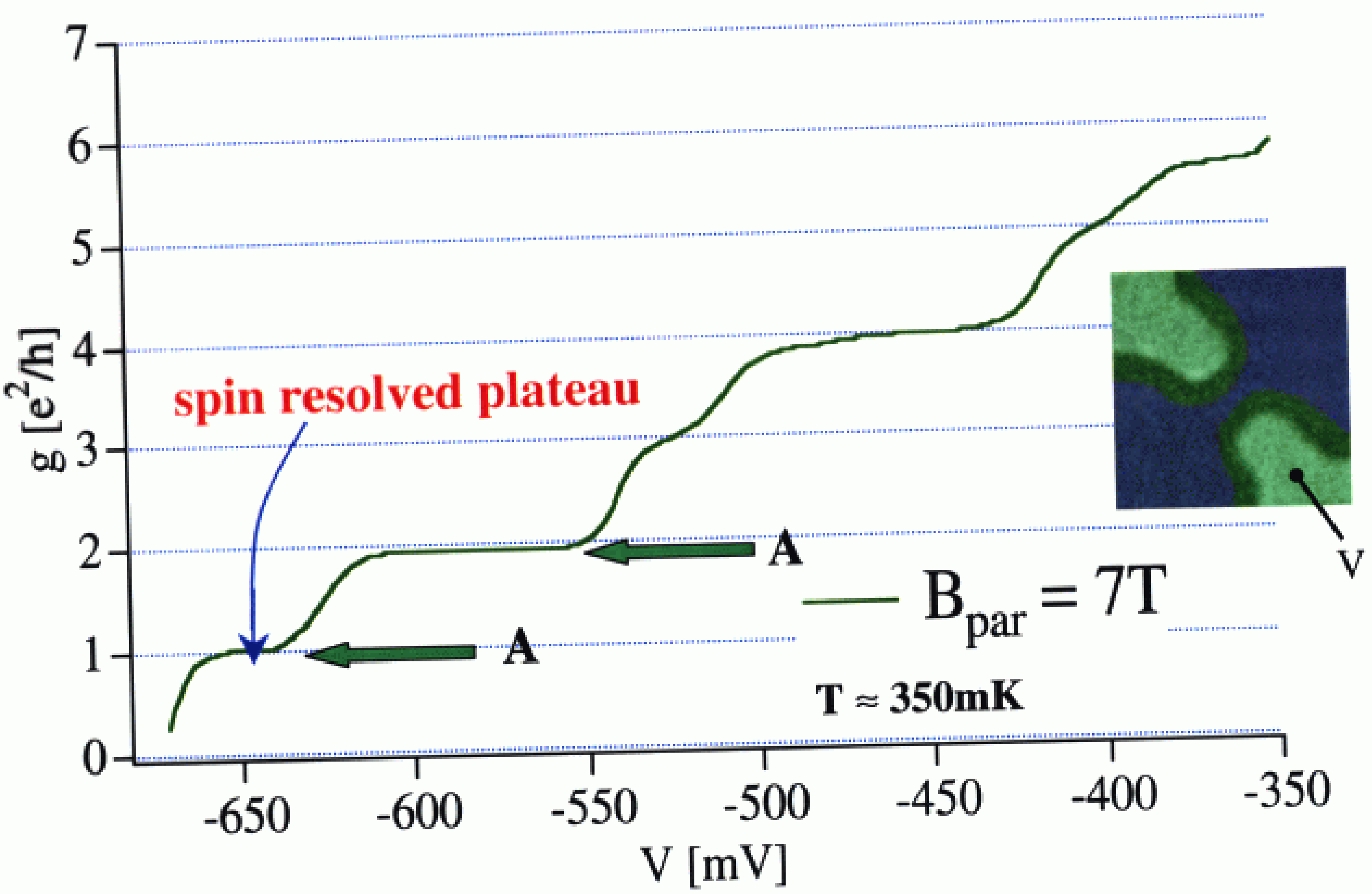
depth of 2DEG	900 Å
carrier density n	$2.8\ 10^{11}\ \mathrm{cm}^{-2}$
Mobility μ	$140{,}000\ \mathrm{cm}^2/\mathrm{Vs}$
mean free path l_e (elastic)	1 μm

small dot		**big dot**	
dot area A_{dot}	$1\ \mu\mathrm{m}^2$	available area	$10{,}000\ \mu\mathrm{m}^2$
level spacing Δ	7 μeV	level spacing Δ	0.7 neV
crossing time τ_{cross}	5 ps	crossing time τ_{cross}	0.5 ns
dwell/escape time τ_{dwell}	0.3 ns	dwell/escape time τ_{dwell}	3 μs





Quantum Point Contact



QPC1: e^2/h plateau (spin resolved)
QPC2: $2e^2/h$ plateau (spin degenerate)

1) IF $\tau_{spin} << \tau_{dwell}$

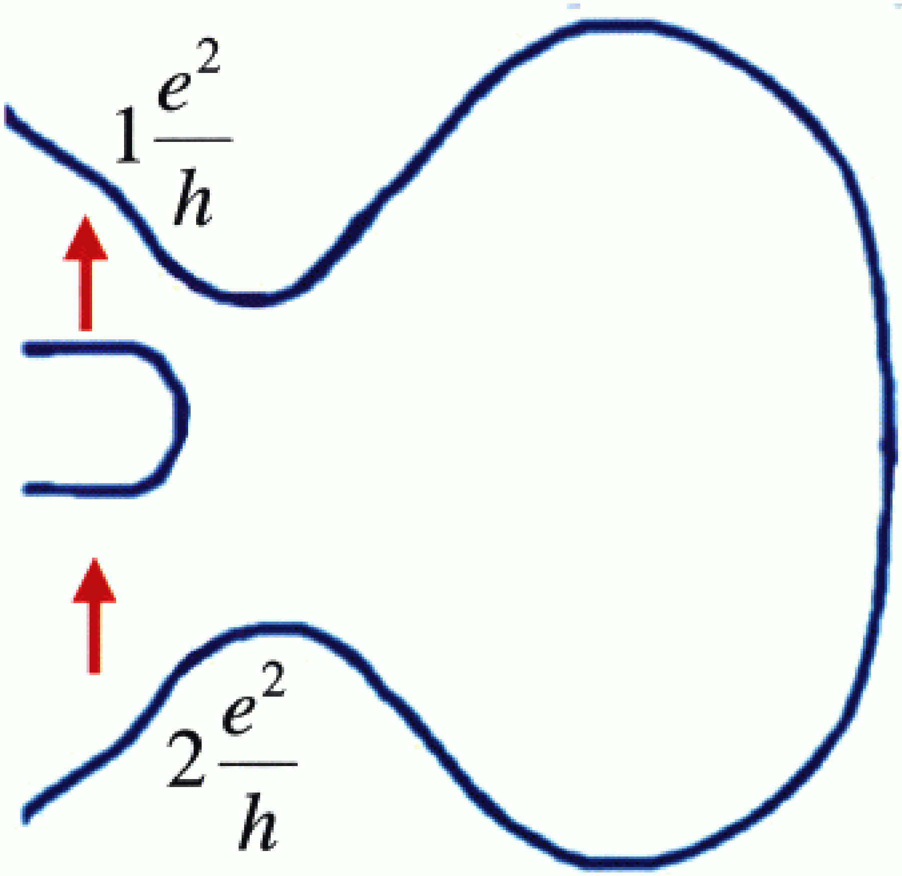
$$\langle G_{ser} \rangle = \left(\left(1\frac{e^2}{h} \right)^{-1} + \left(2\frac{e^2}{h} \right)^{-1} \right)^{-1} = \frac{2}{3}\frac{e^2}{h}$$

1, 2 **channels** --> **2/3**

2) IF $\tau_{spin} >> \tau_{dwell}$

$$\langle G_{ser} \rangle = \left(\left(1\frac{e^2}{h} \right)^{-1} + \left(1\frac{e^2}{h} \right)^{-1} \right)^{-1} = \frac{1}{2}\frac{e^2}{h}$$

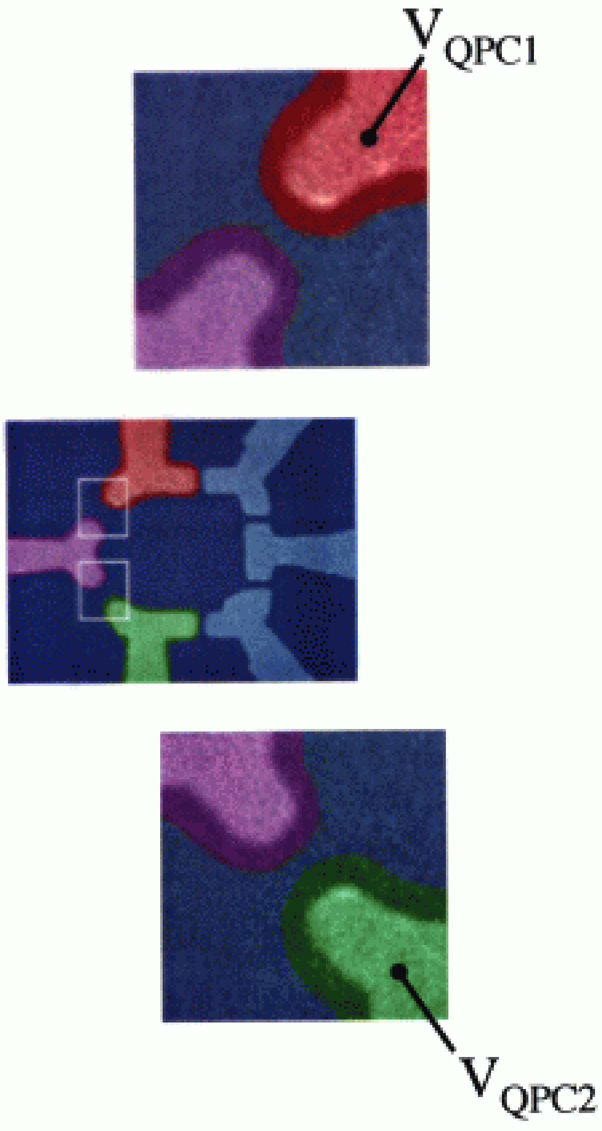
1, 1 **channels** --> **1/2**

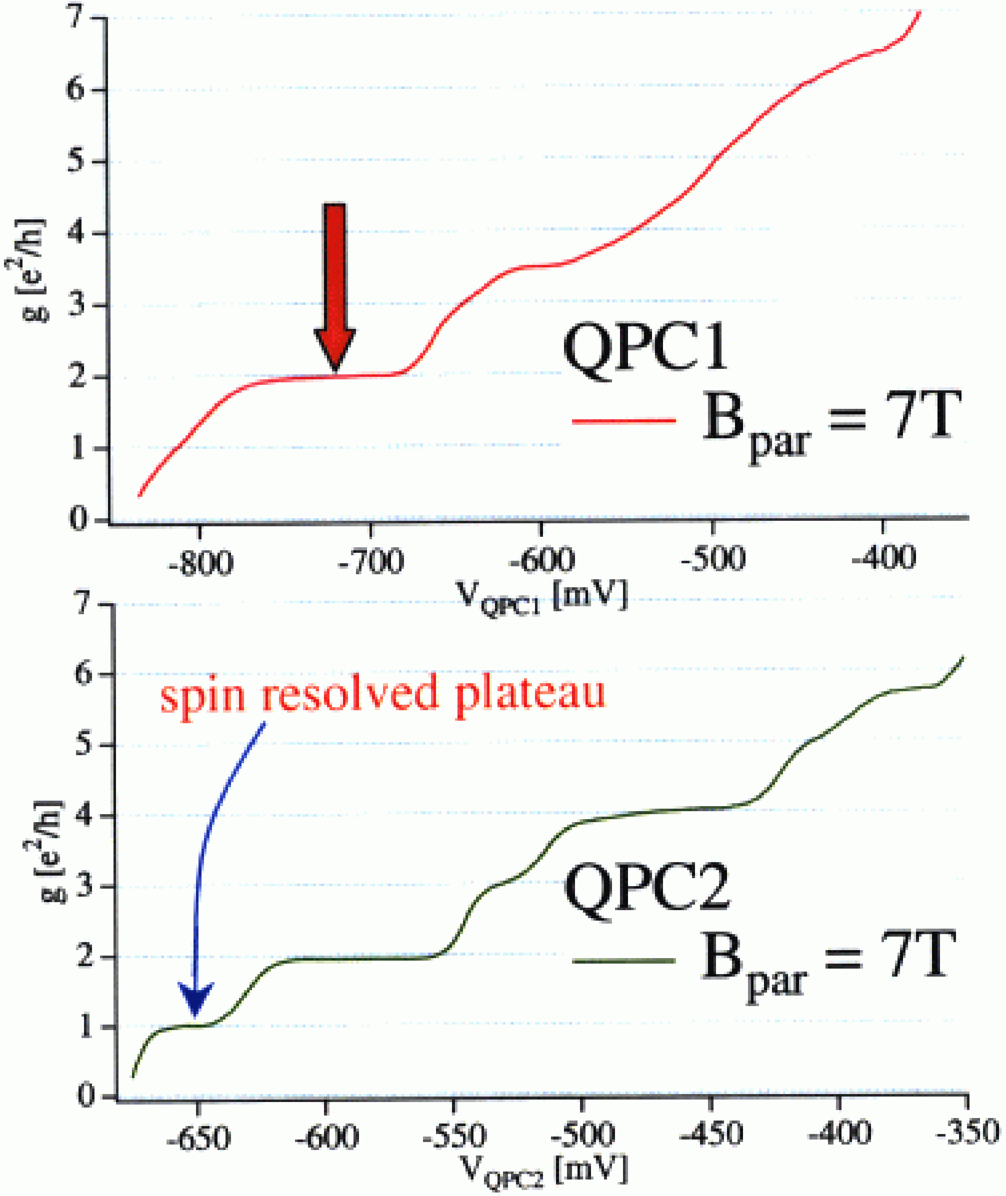


correct including quantum interference and electron-electron interactions

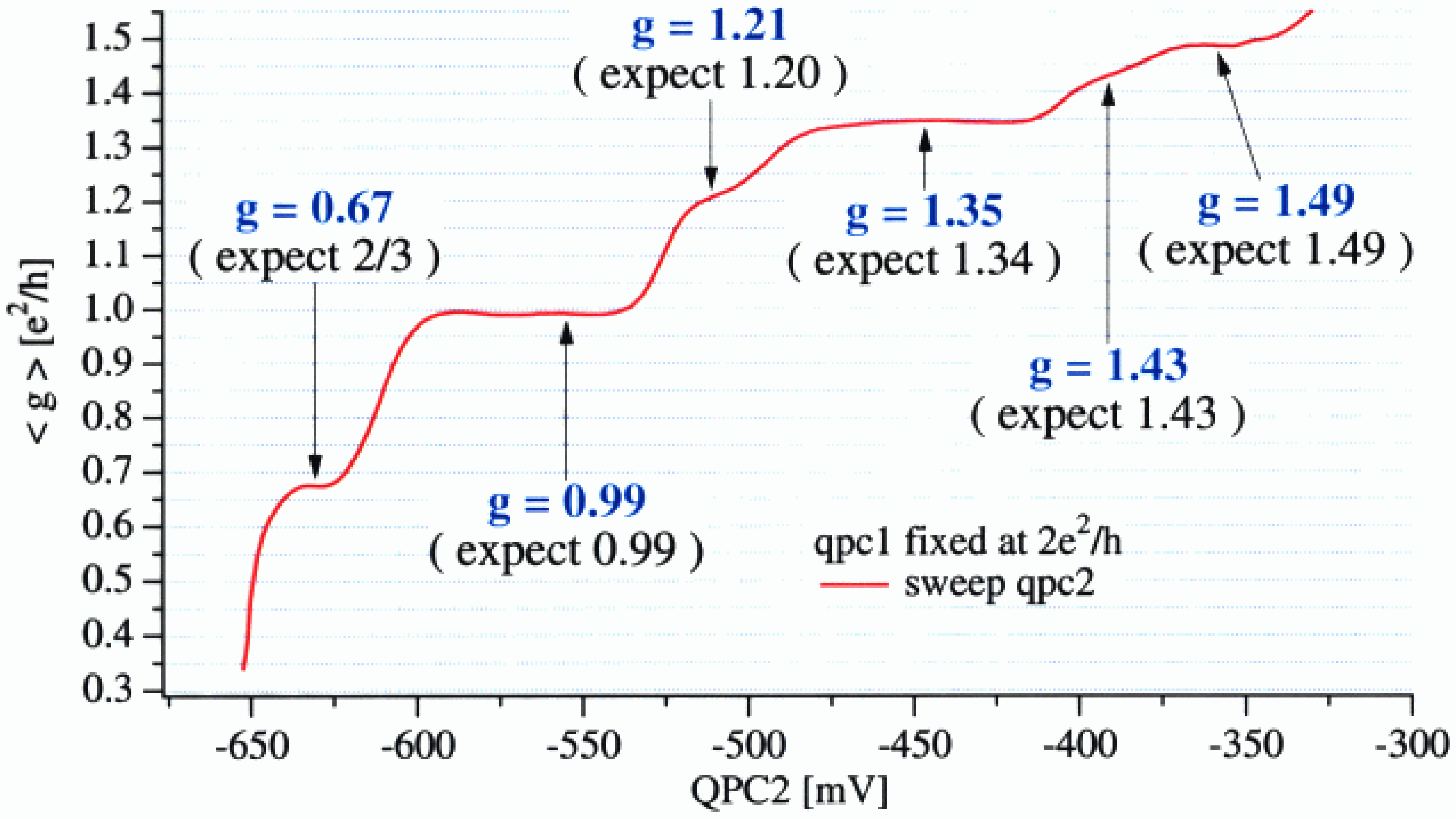
QPC1: e^2/h plateau (spin resolved)
QPC2: $2e^2/h$ plateau (spin degenerate)

B = 7T



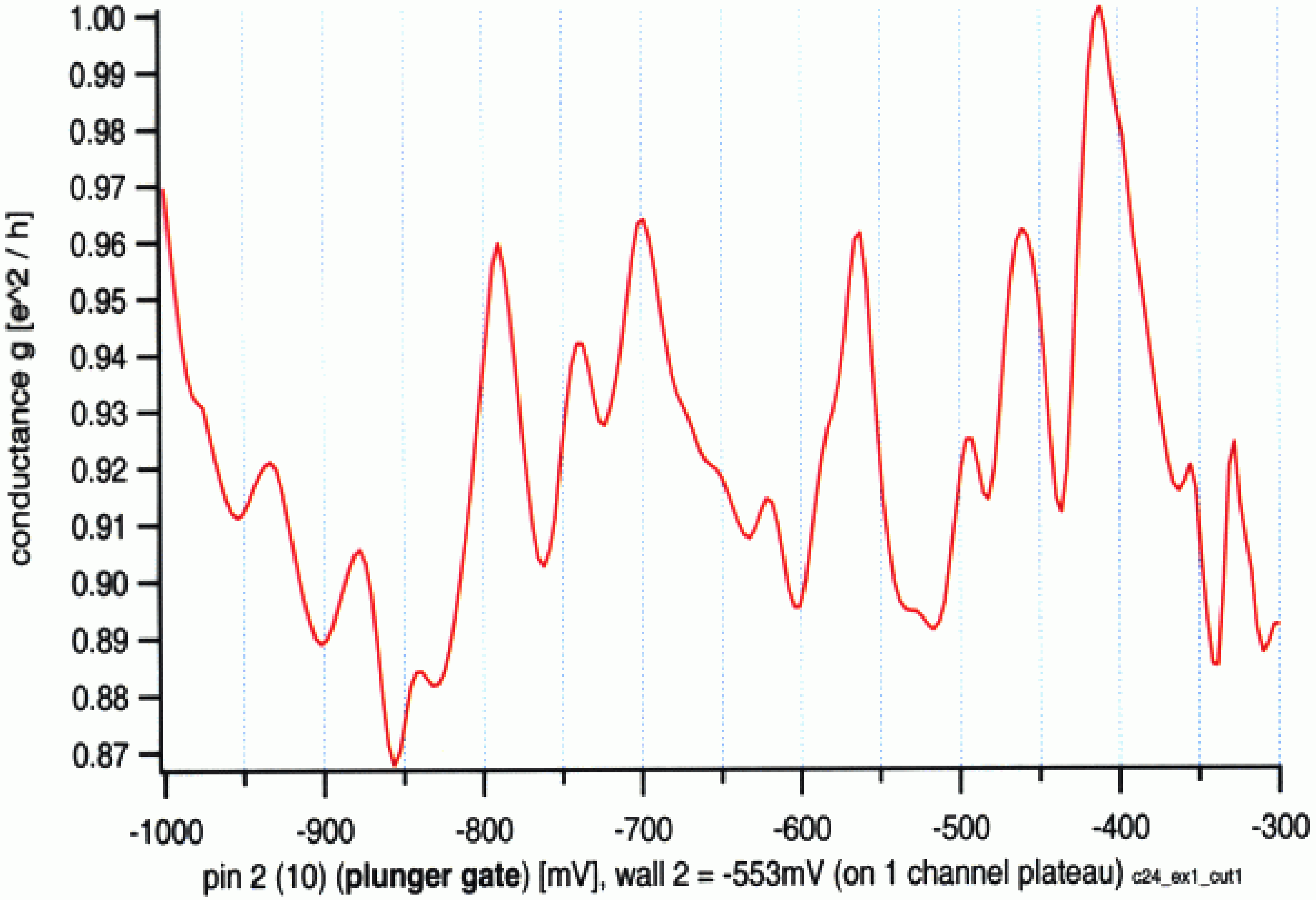


The Experiment: BIG DOT

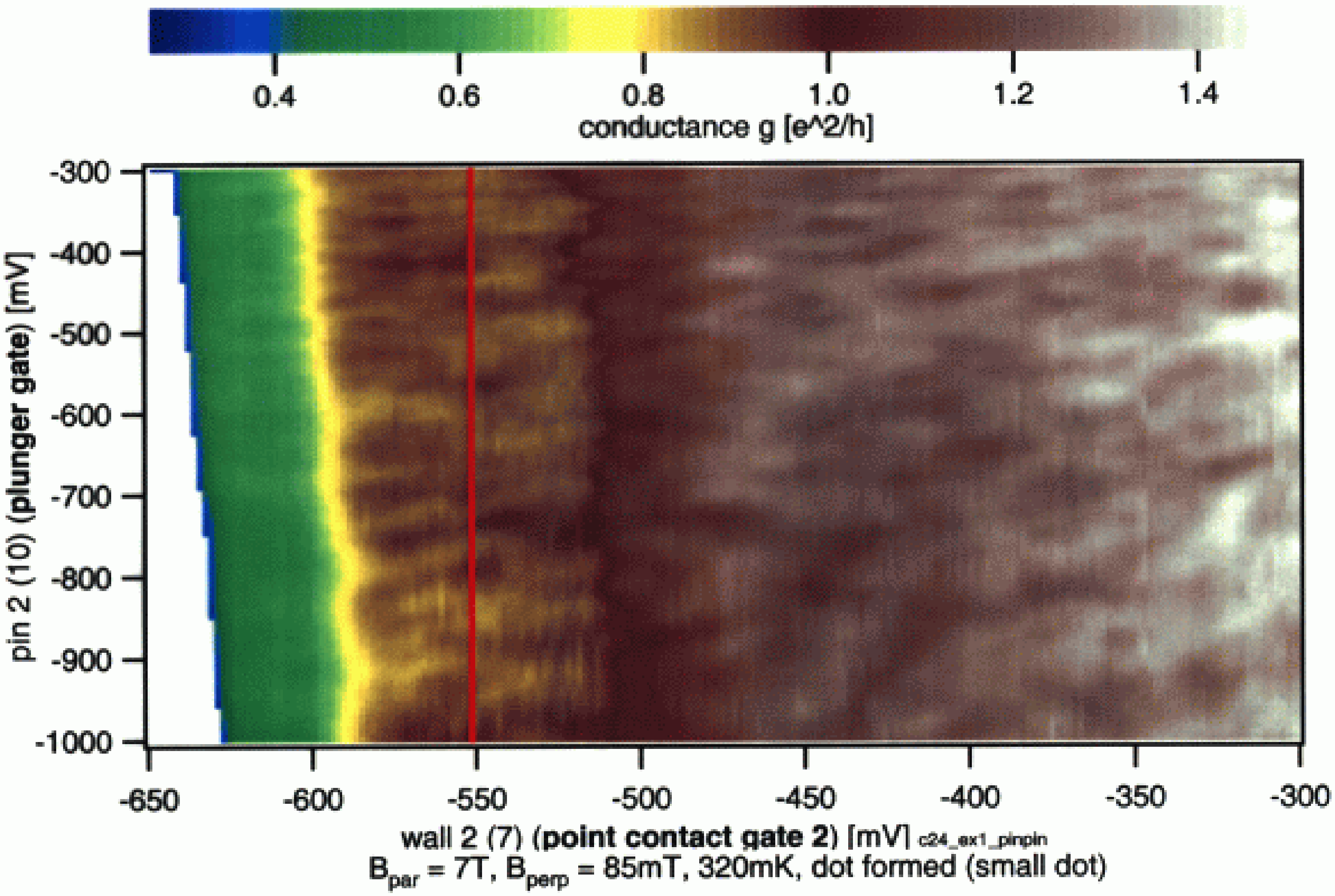


B_{par} =7T B_{perp} =85mT T = 350mK

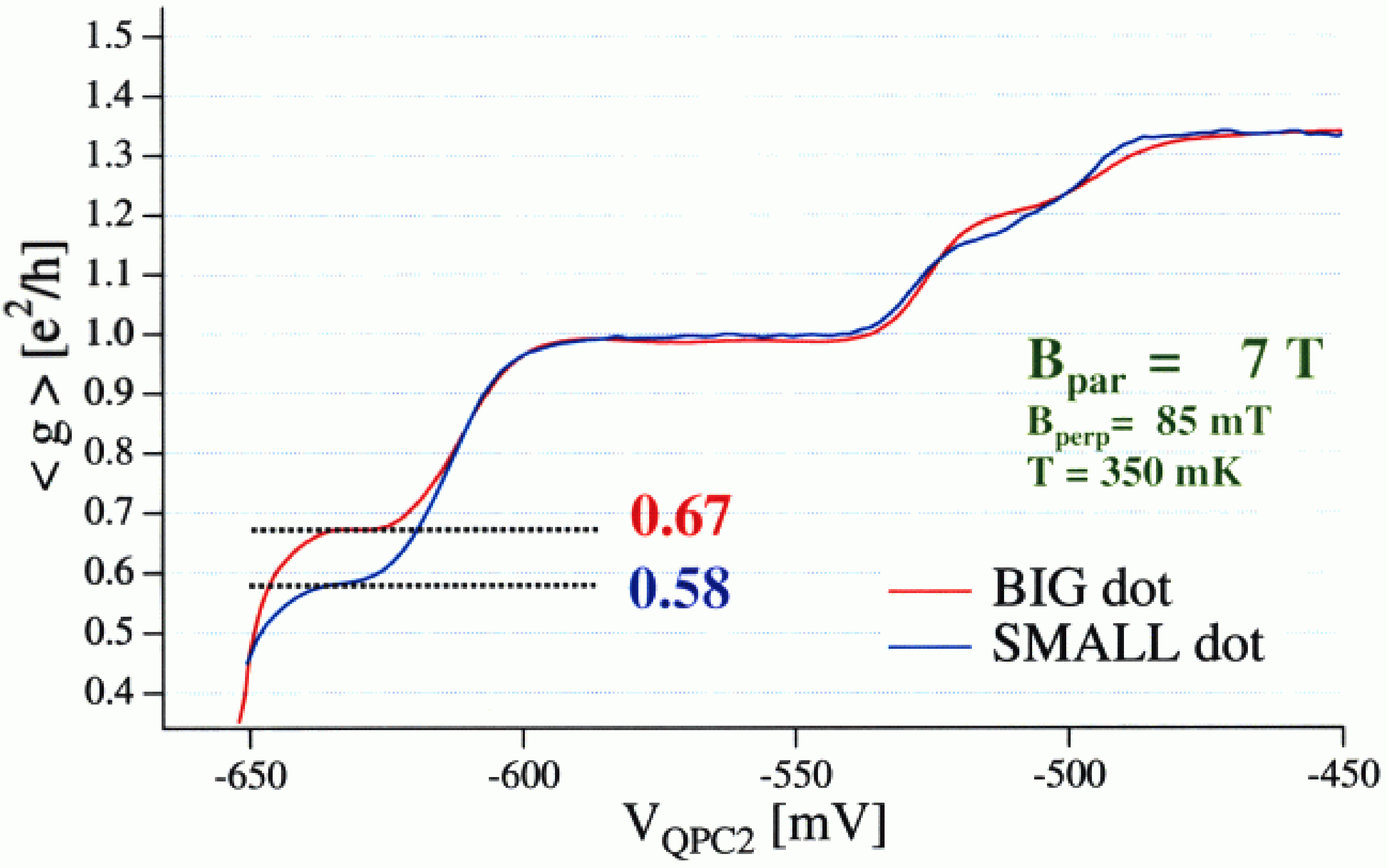
Universal conductance fluctuations



Universal conductance fluctuations: the big picture



Comparison: BIG dot vs SMALL dot



Interpretation

BIG dot:

$\langle g \rangle$ measured = 0.67 ($\approx$2/3)

→ $\tau_{\text{spin}} << \tau_{\text{dwell}} \approx 3\ \mu\text{s}$

SMALL dot:

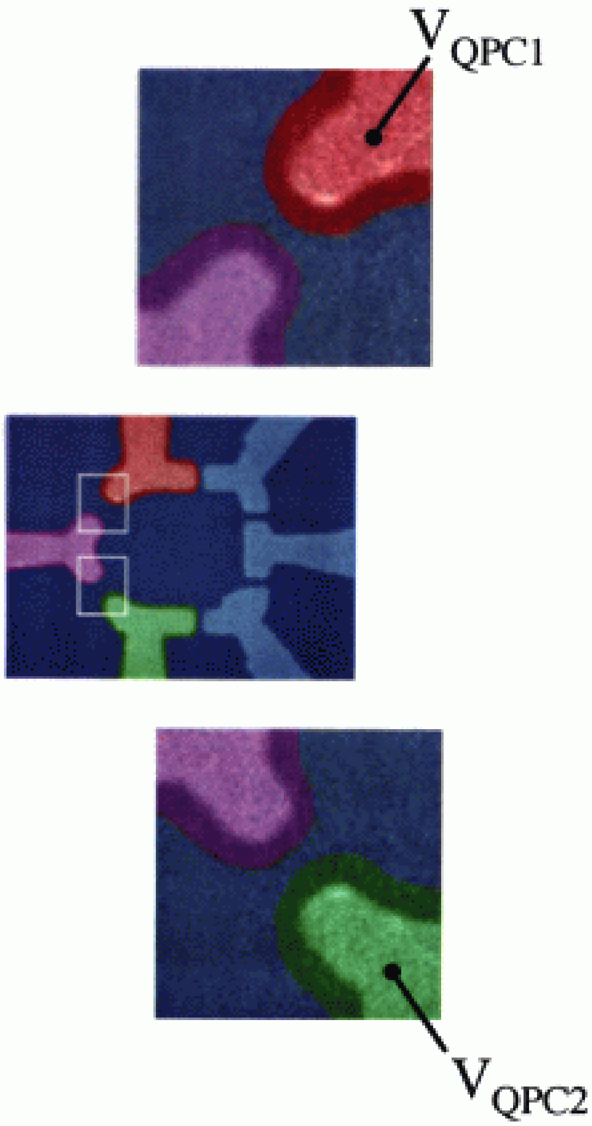
$\langle g \rangle$ measured = 0.58 (>0.5)

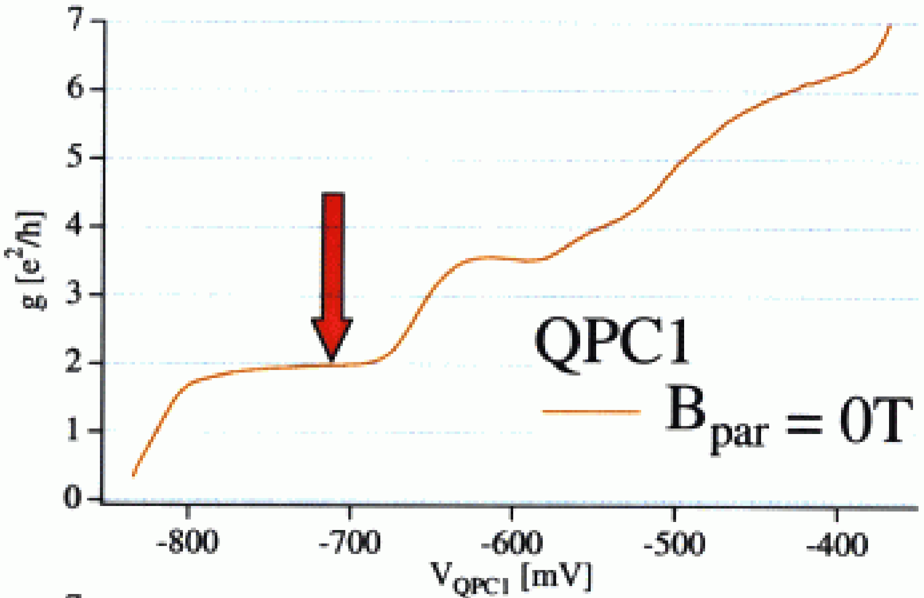
→ $\tau_{\text{spin}} \geq \tau_{\text{dwell}} \approx 0.3$ ns

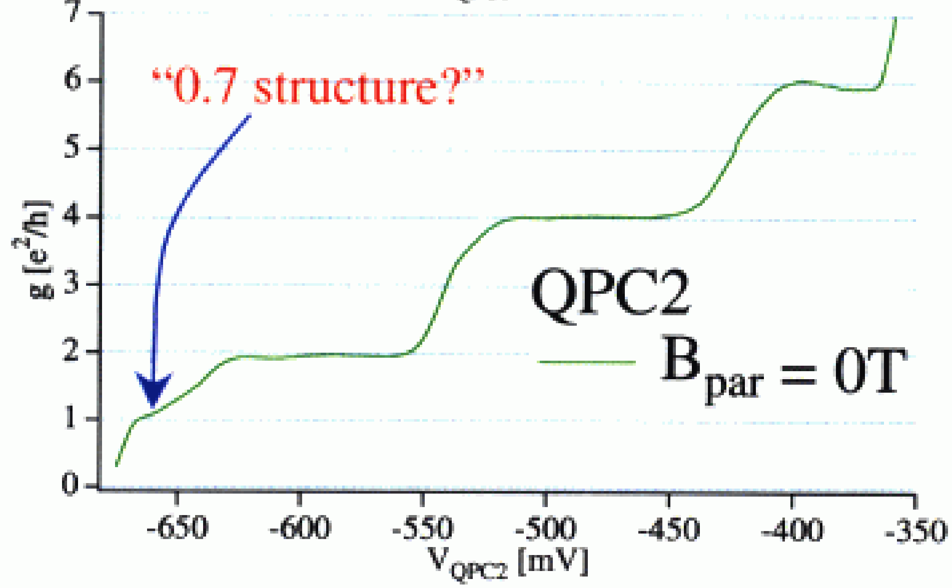
quantitative analysis: $\tau_{\text{spin}} \approx 1.5$ ns
(spin selective Landauer formula, ...)

QPC1: e^2/h plateau (spin resolved)
QPC2: $2e^2/h$ plateau (spin degenerate)

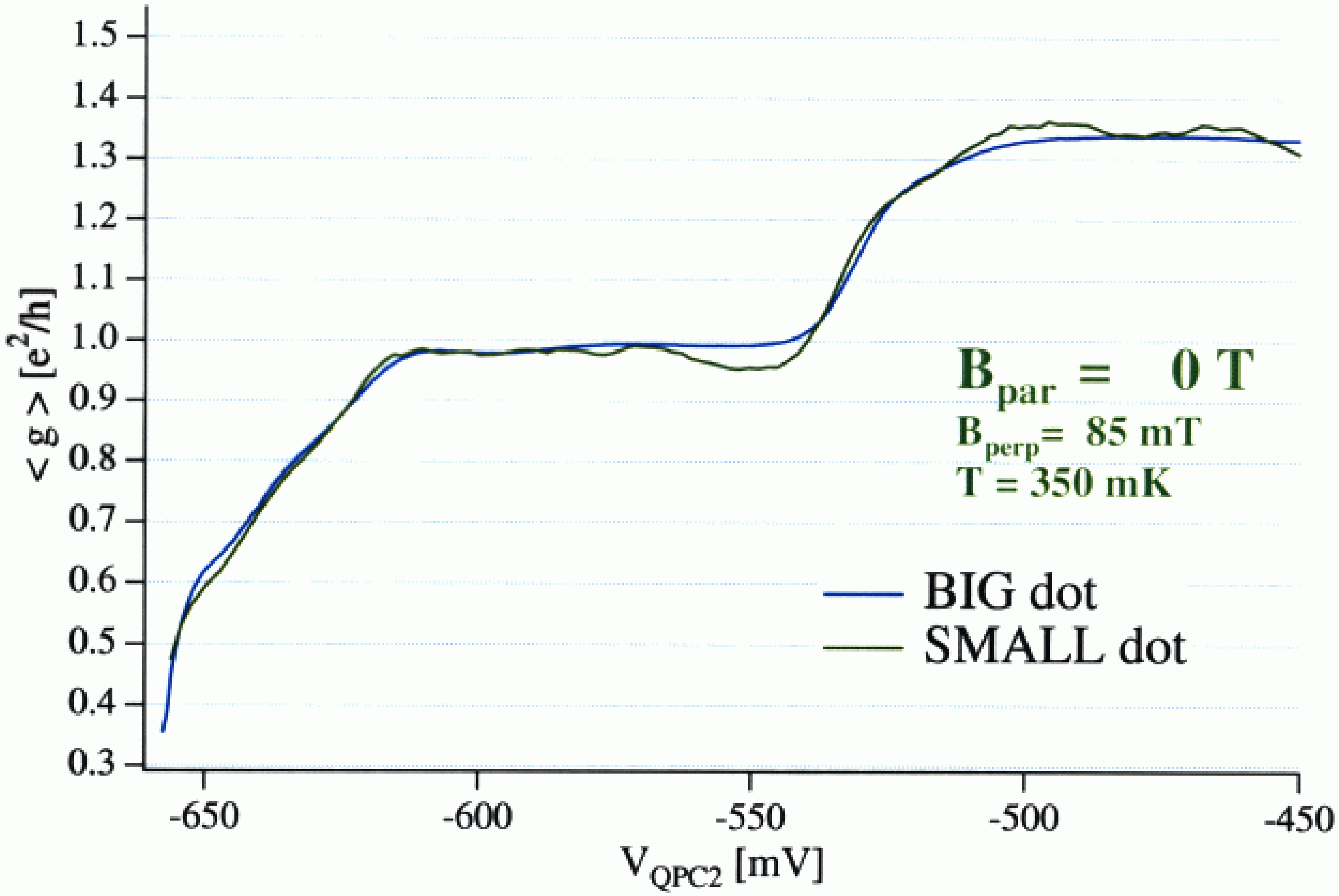
B = 0T







Comparison, BIG vs SMALL dot B = 0T



Conclusion

- *introduced a new technique to investigate spin effects in GaAs quantum dots*
- *put bounds on τ_{spin} in GaAs quantum dots*

Future Application

spin orbit scattering in 2DEGs

GaAs heterostructure: $\tau_{\mathrm{s.o.}} > \tau_{\phi}$ (observed localization, not
antilocalization); also $\tau_{\mathrm{s.o..}} > \tau_{\mathrm{spin}}$
knowing $\tau_{\mathrm{spin\text{-}relax}}$ puts a lower boundary on $\tau_{\mathrm{s.o..}}$