Quantum Transport in Ballistic Cavities Subject to a Strictly Parallel Magnetic Field

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Motivations for this work

- Interest for ballistic and phase coherent electron dynamics in mesoscopic systems.
- Effect of an in-plane B on the transport properties (universal conductance fluctuations) of an open quantum dot.
- Influence of the 2DEG confinement potential and finite thickness (orbital motion).

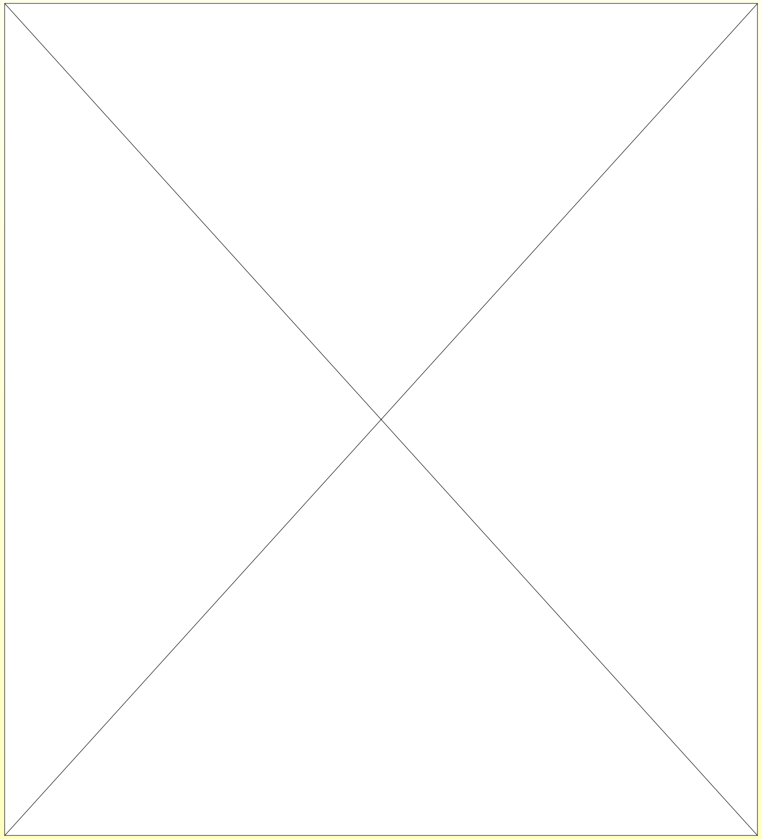
Devices Fabrication

- $GaAs/Al_{0.3}Ga_{0.7}As$ delta-doped Quantum Wells

	Narrow QW	Wide QW
QW thickness	15 nm	45 nm
Density	$2\ 10^{11}\ cm^{-2}$	$3\ 10^{11}\ cm^{-2}$
Location (below surface)	100 nm	150 nm
Mobility	$6\ 10^{5}\ cm^{2}/Vs$	$2\ 10^{6}\ cm^{2}/Vs$
Occupied Subbands	1	2

- SEM lithography
- Cr-Au depletion gates
- $3\mu m^2$ billiard

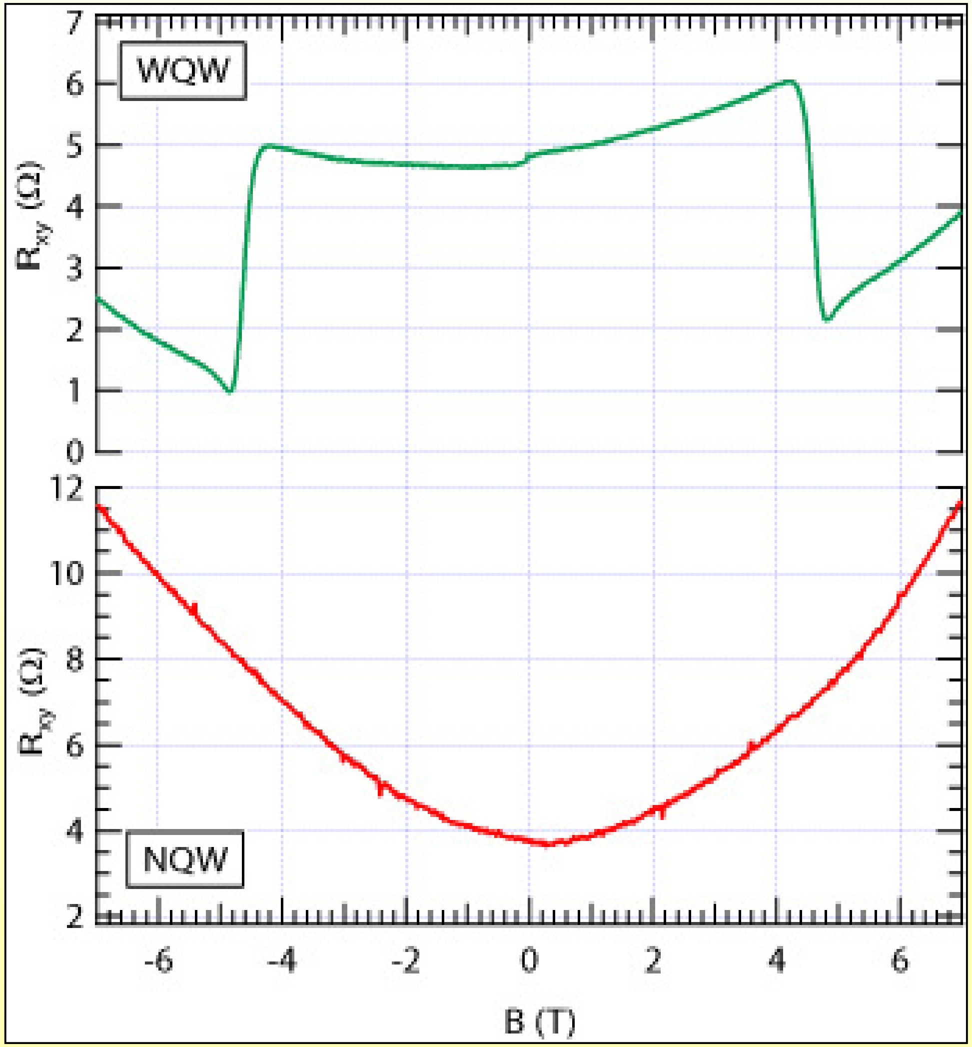
Experimental Setup



- Measurements in a 3He refrigerator at 300mK
- Standard lock-in technique at I=1nA

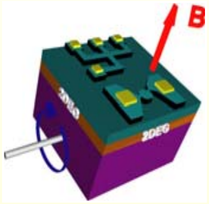
- *In situ* Tilting of the magnetic field
- Second Hall bar on wafer for precise B alignment and tilt angle measurement

Measuring the tilt angle



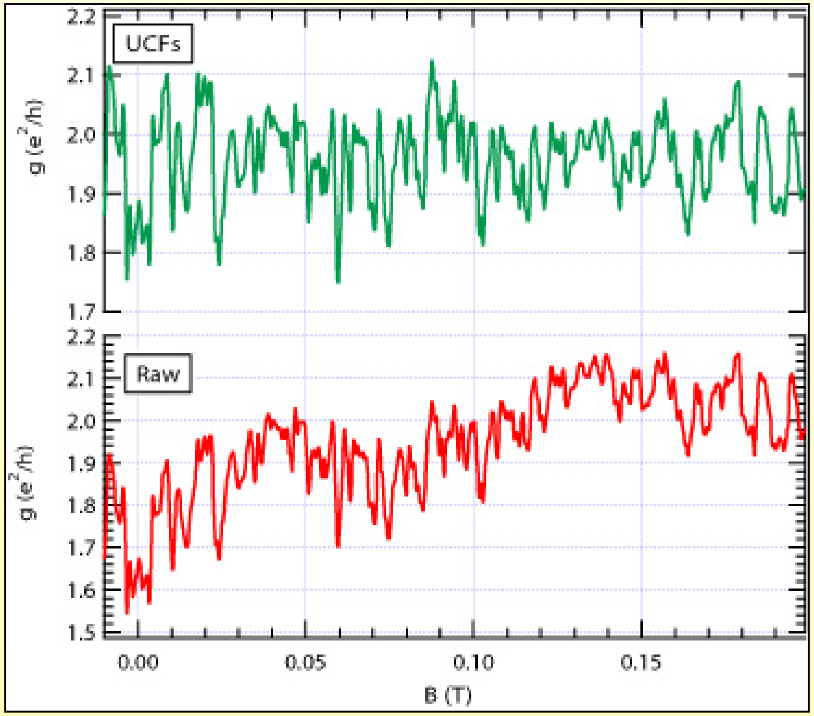
- Second Hall Bar adjacent to Open dot (150 µm)
- Slope of R_{xy} proportional to tilt angle
- Θ=90° : R_{xy} symetric in B
- Residual R_{xx} at B=0T taken into account
- Precision : 0.01°
- WQW : Drop in R_{xy} around B=4.5T

Universal Conductance Fluctuations

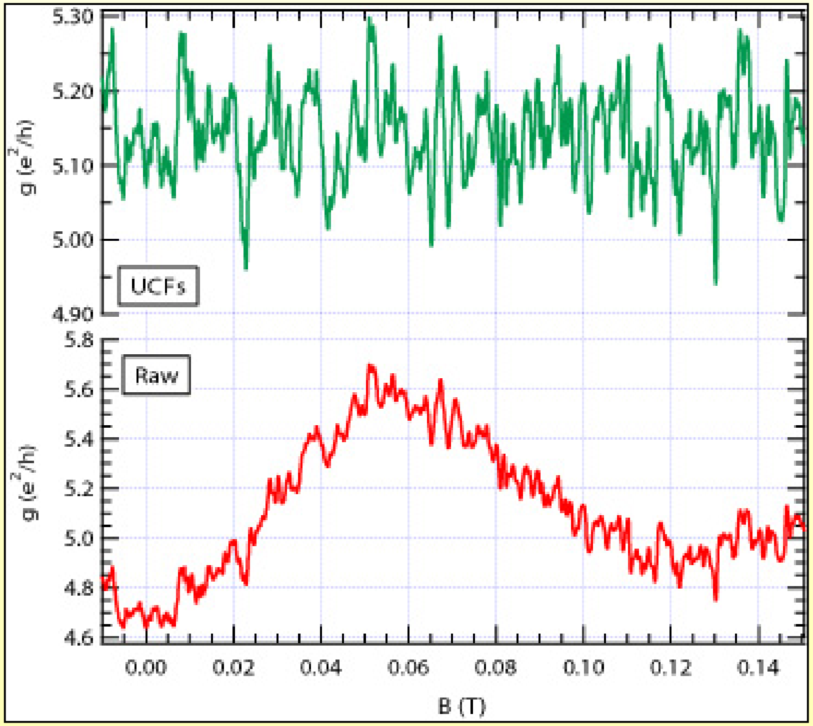


- Perpendicular field
- Low-pass filter to isolate UCFs

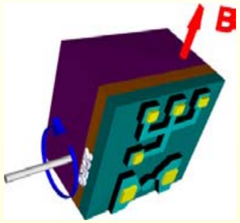
Narrow Quantum Well



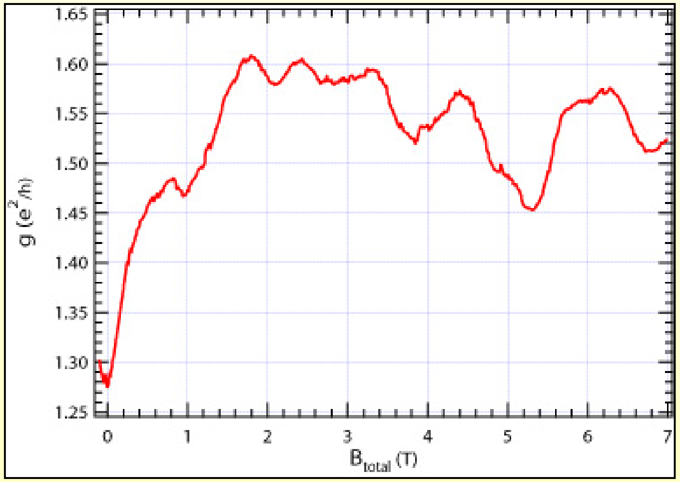
Wide Quantum Well



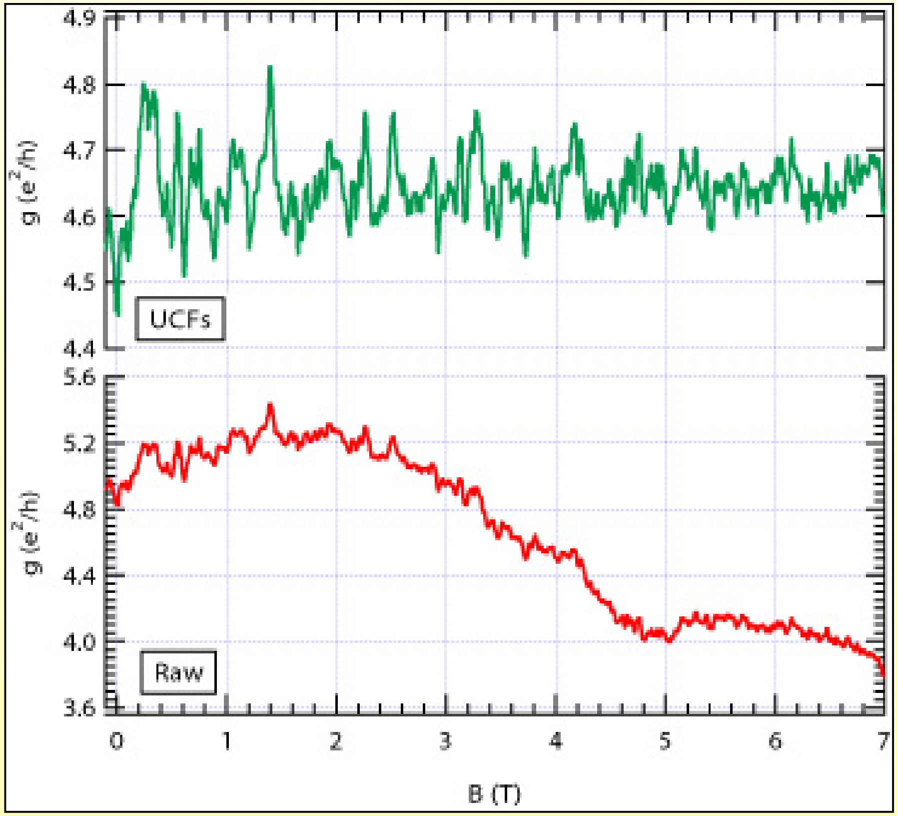
Tilting the sample : θ=90°



Narrow Quantum Well

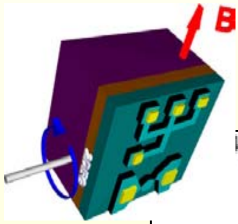


Wide Quantum Well

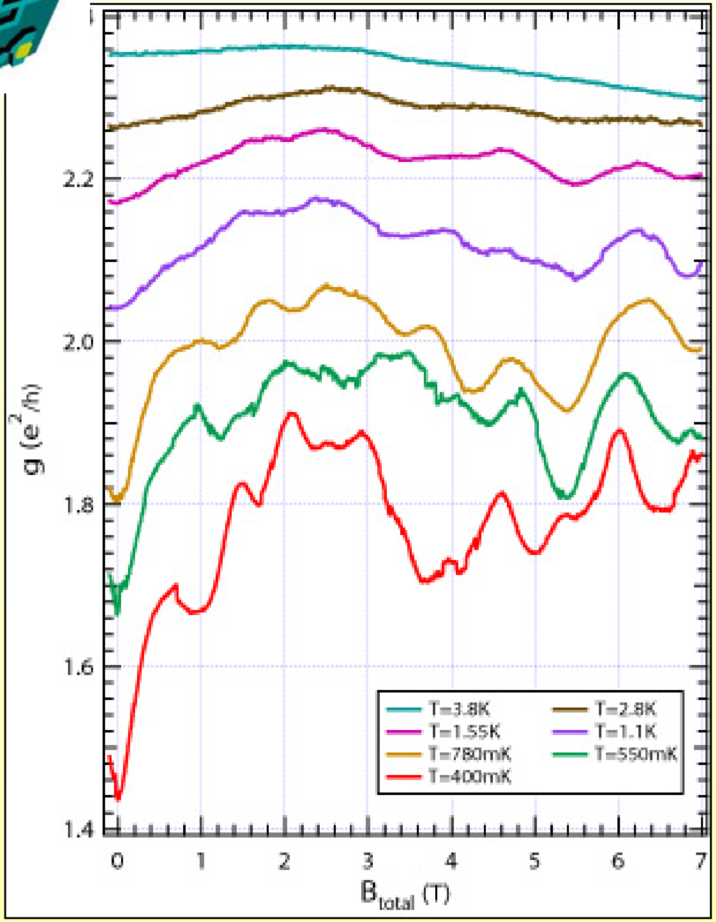


- UCFs under a pure parallel magnetic field
- Fluctuations frequency much smaller in the narrow QW
- Conductance drop in WQW – 4T
- WQW : Comparison with high T curve $\Rightarrow$ looking at high frequencies only f_{cutoff}=0.5Hz

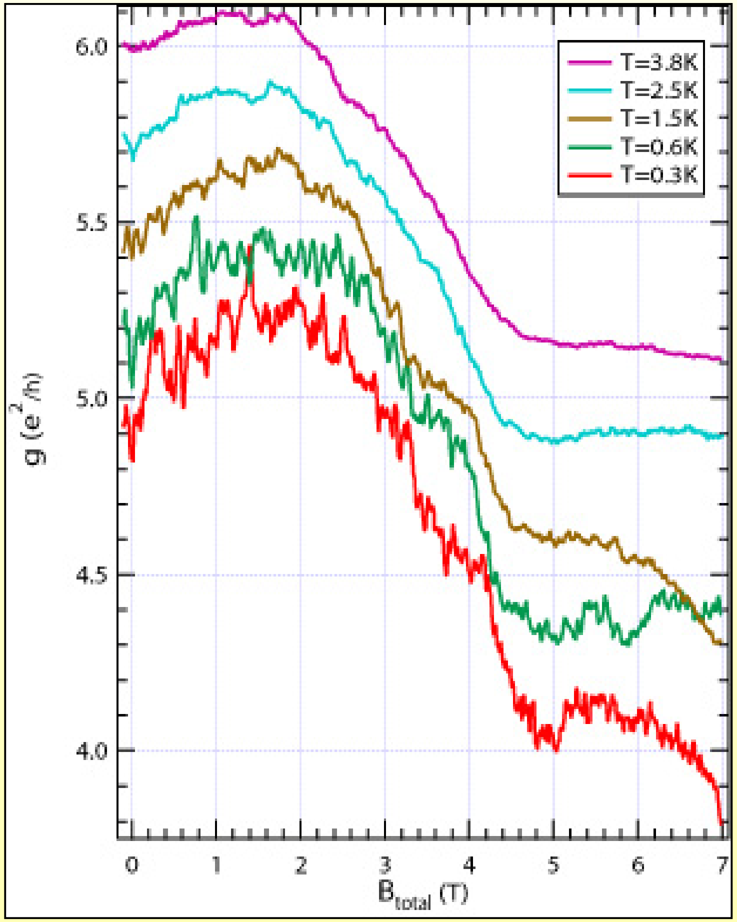
θ=90° : Temperature Dependence



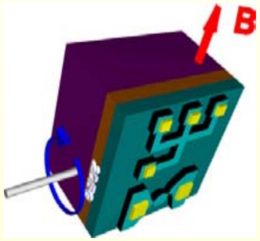
Narrow Quantum Well

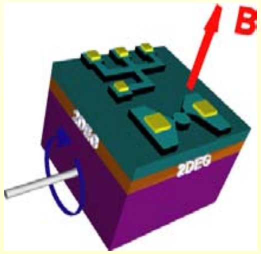


Wide Quantum Well

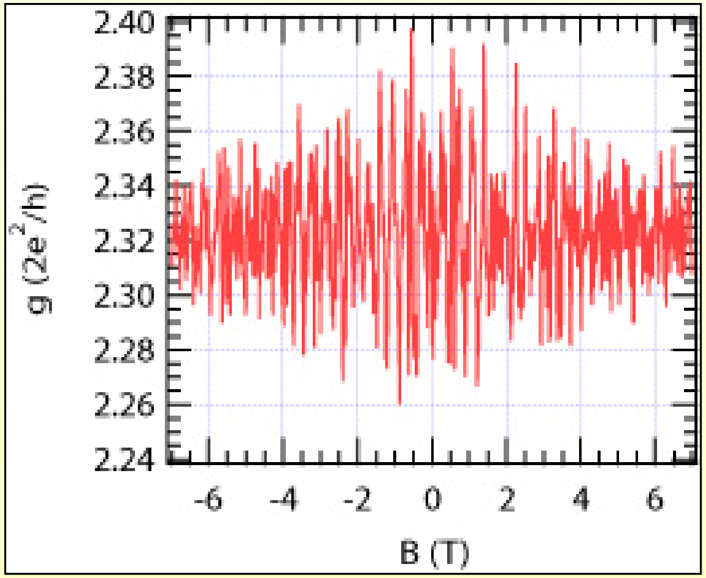


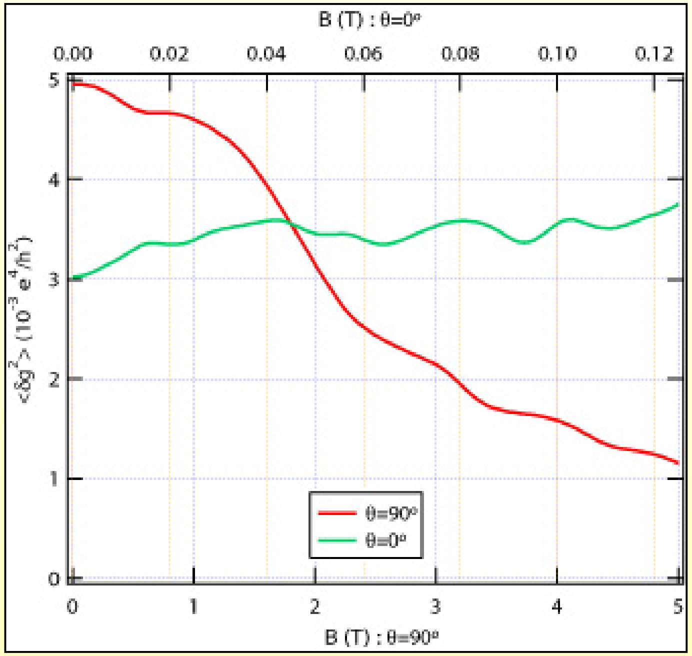
Fluctuations Statistics : Variance





Wide Quantum Well





- UCFs only : High T (>3K) magnetoresistance removed
- Comparison between Variances at θ=0° and θ=90°
- Variance decreases as a function of $B_{//}$ (factor 3.5-5) depending on gate voltage

Possible ingredients

- 2DEG finite thickness : Electrons "bouncing" on confinement potential walls.

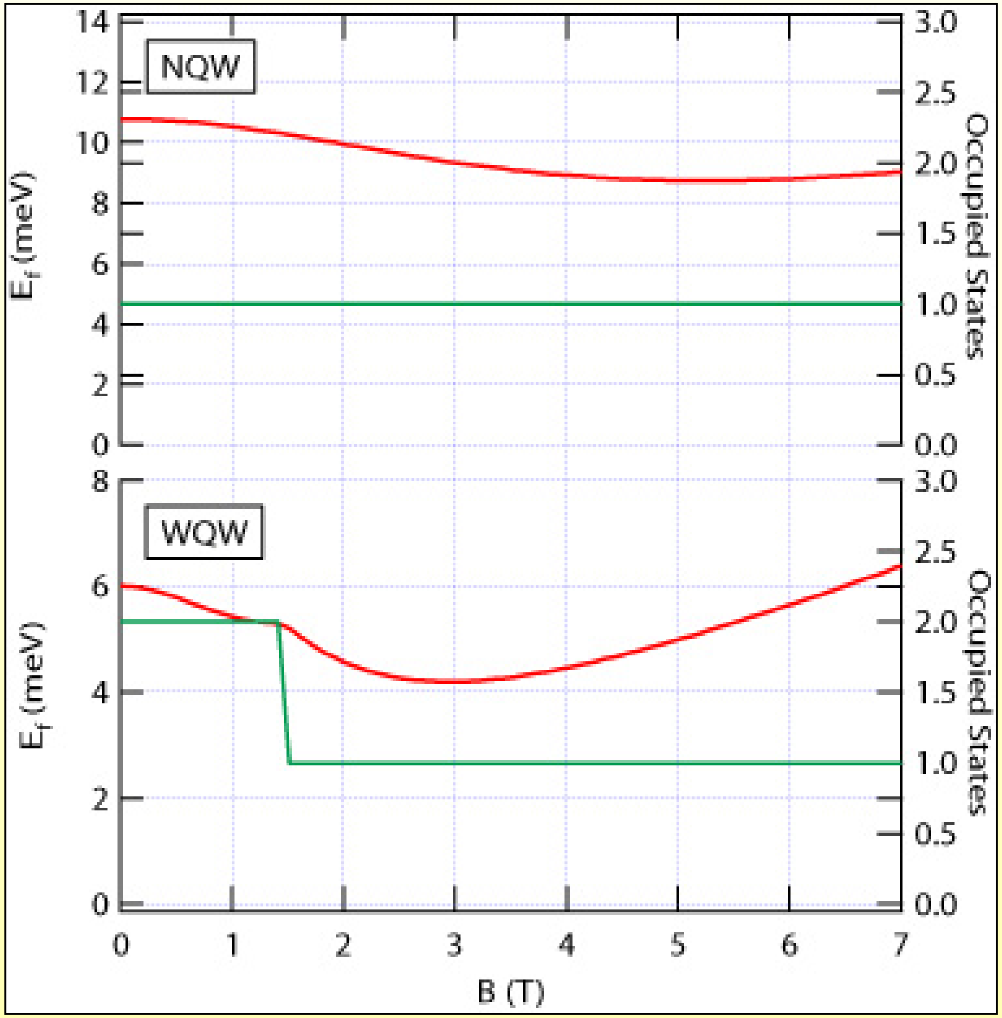
- Zeeman Energy and SO Coupling : produce a variance reduction in $B_{//}$ by a factor of 4
  Folk *et al.* , Phys. Rev. Lett., **86**, 2102 (2001)
  Halperin *et al.* , Phys. Rev. Lett., **86**, 2106 (2001)

- Orbital effect : $B_{//}$ renormalizes m_{eff}, changes E_F (parabolic in $B_{//}$), lifts the symmetry of the dispersion law E(k).
  Fal'ko *et al.* , Phys. Rev. B, 65, 81306R (2002)
  Meyer *et al.* , Phys. Rev. Lett., 89, 206601 (2002)
  Smrcka *et al.* , Phys. Rev. B, 51, 18011 (1995)

$$m_{eff} \rightarrow m_{eff}\left(1+\frac{\omega_c^2}{\omega_0^2}\right)$$

$$\omega_c = \frac{eB_{//}}{m_{eff}}$$

Subband depopulation – simple model

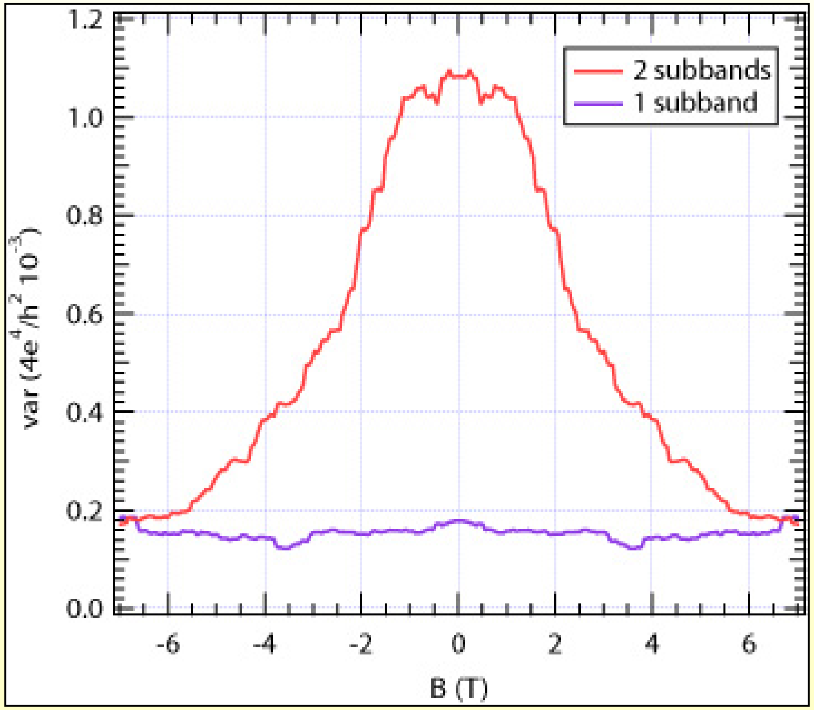


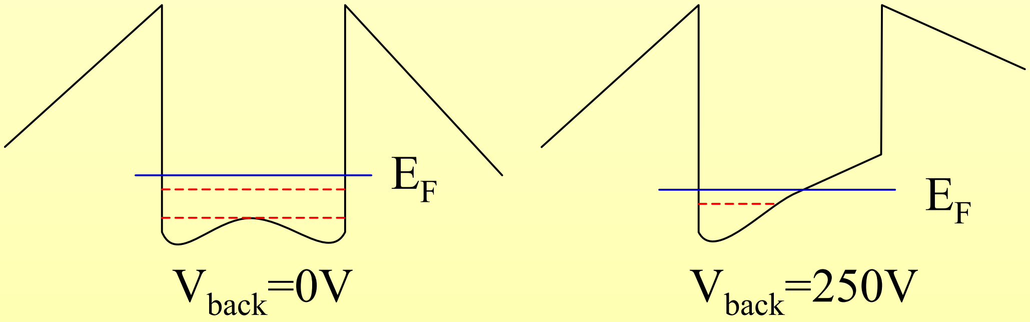
- **Simple Model :**
  1. Constant density
  2. 2DEG only
  3. Parabolic confinement potential
  4. No thermal smearing
- **Self-Consistent :**

  WQW : Upper subband depopulation first

  Heisz *et al.* , Phys. Rev. B, 53, 13594 (1996)

Wide Quantum Well : From 2 to 1 subband

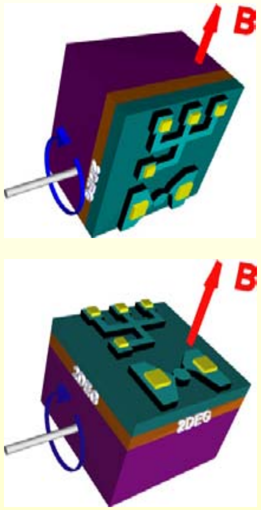


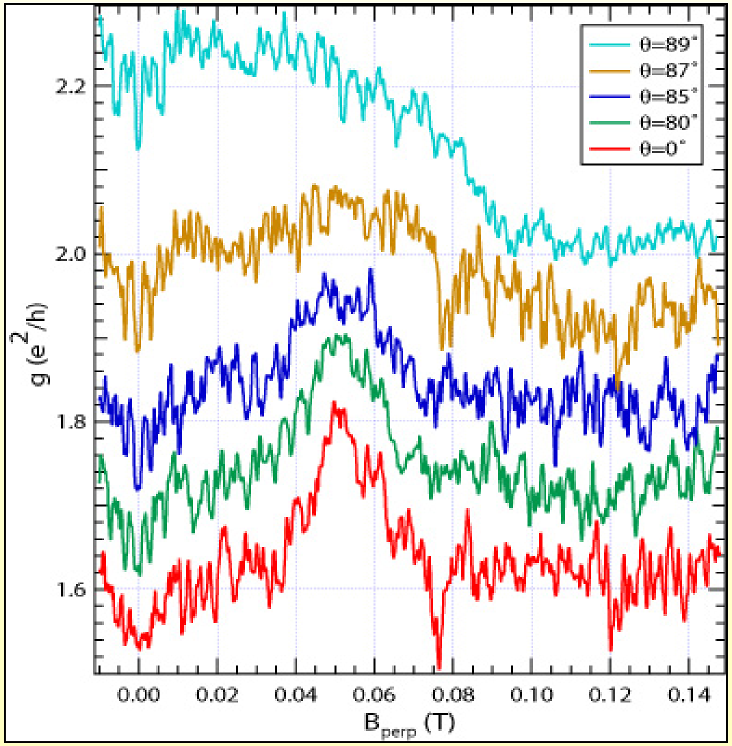


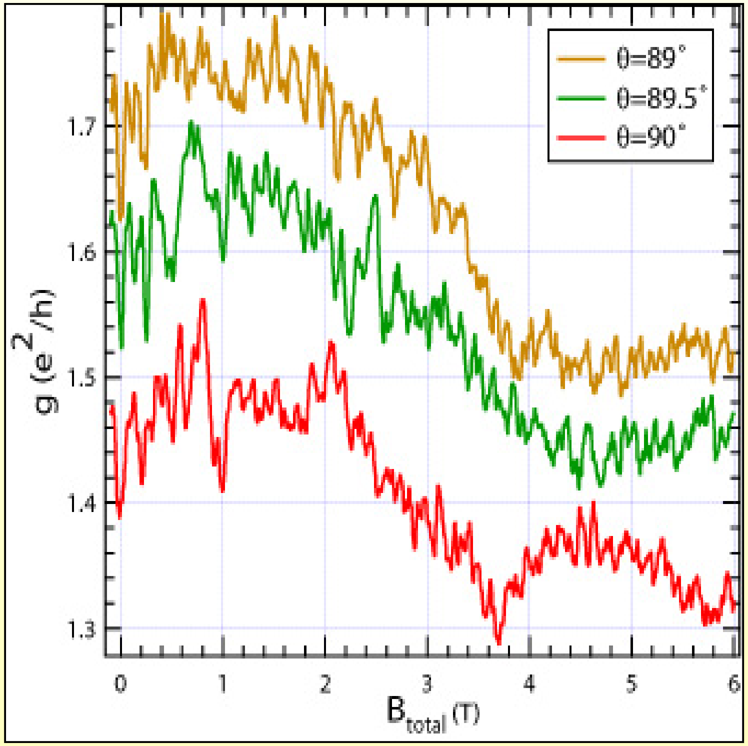
- 1 subband : variance is constant and equal to the value at high $B_{//}$ for 2 subbands.
- No variance reduction with 1 subband

UCFs at Intermediate Angles

Wide Quantum Well

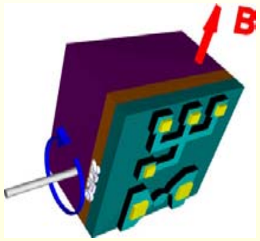




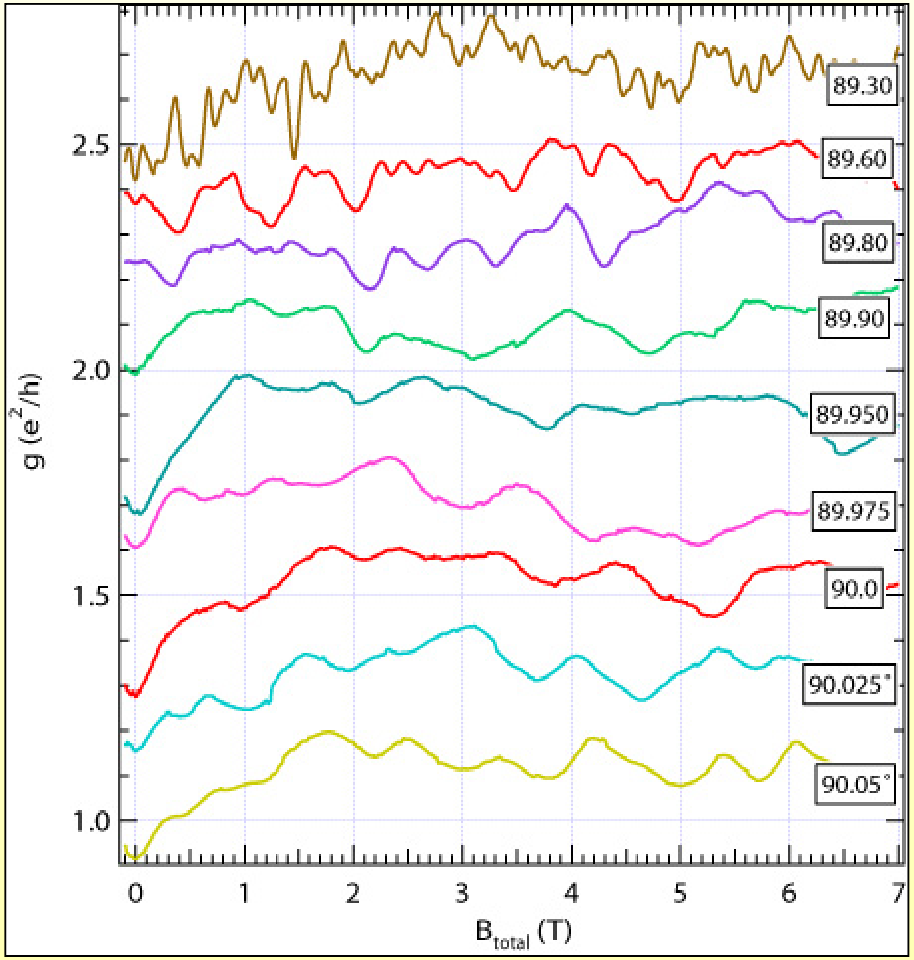


- Intermediate tilt angles : subband depopulation
- High tilt angles : No apparent decrease in UCFs frequency

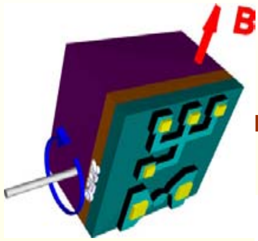
UCFs at Intermediate Angles (2)



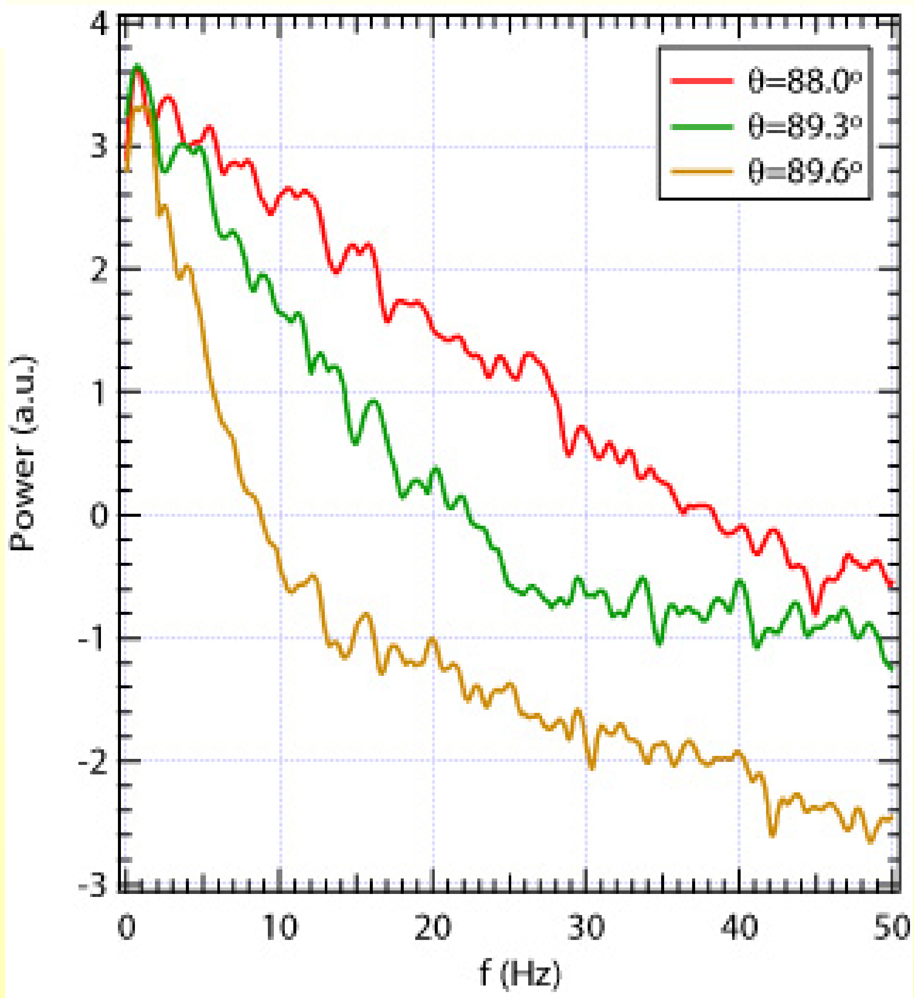
Narrow Quantum Well



- Approaching 90° :oscillations frequency decreases
- Near 90° : both frequency and amplitude saturate



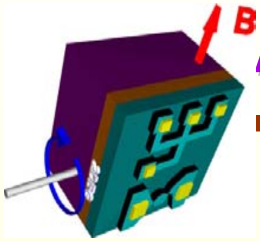
Angle from Power Spectrum



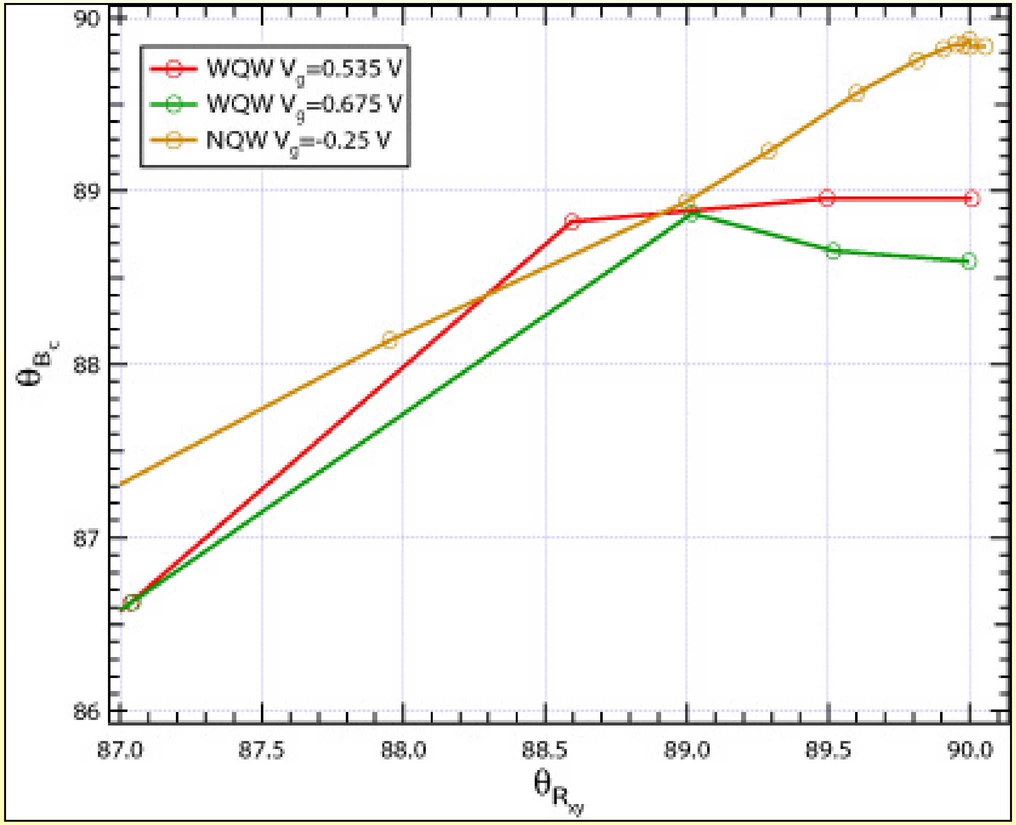
- Evaluation of correlation field B_c at intermediate tilt angle

$$S(f) = S(0)\ e^{-2\pi B_c f}$$

- Comparison with B_c at θ=0° (perpendicular field)
  ❾ influence of $B_{//}$ on UCFs statistics



Angle from Power Spectrum (2)



- Narrow QW : saturation around θ=89.9°
- Wide QW : saturation below θ=89°
- WQW - 90° : factor 100 in Bc (possible orbital effect)
- NQW - 90° : factor 1000 in Bc (not comnsistent with an orbital effect…)

Variance as a function of field : Wide QW

1. M going from 2 to 1 $\Rightarrow$ reduction in variance by a factor of 4 : *Zeeman and SO coupling* might play a role BUT with 1 occupied subband, no further variance reduction is observed !
2. Uncoupled subbands : complete depopulation of upper subband at B=7T. Only lower subband contribute to variance.
3. Why such a large contribution from the upper subband ?
4. Could be consistent with finite thickness effect due to semiclassical orbits

Parallel field induced oscillations : Narrow QW

1. Mass renormalization and E_F variation expected to be smaller with narrow confinement potential : lower frequency oscillations induced by $B_{//}$
2. Confinement potential symmetric -> No time-reversal symmetry breaking expected : Variance remains constant
3. Data are not consistent with finite thickness effect due to semiclassical orbits

Conclusions

- Anomalous conductance fluctuations in a parallel magnetic field
- Strong effect of confinement potential
  1. Wide Quantum Well :
     1. Fast oscillating conductance
     2. Variance in pure $B_{//}$ decreases by a factor of 4 at high field.
     3. One-subband: variance is constant in field
  2. Narrow Quantum Well :
     1. very low frequency oscillations at θ=90°
- Possible ingredients :
  - Semi-classical trajectories
  - Orbital effect with time-reversal symmetry breaking
  - 2DEG subband depopulation