Measurement of the coherence length in the edge states of the Integer Quantum Hall Regime

Nanoelectronics group (CEA, Saclay) & Phynano team (LPN-CNRS, Marcoussis)

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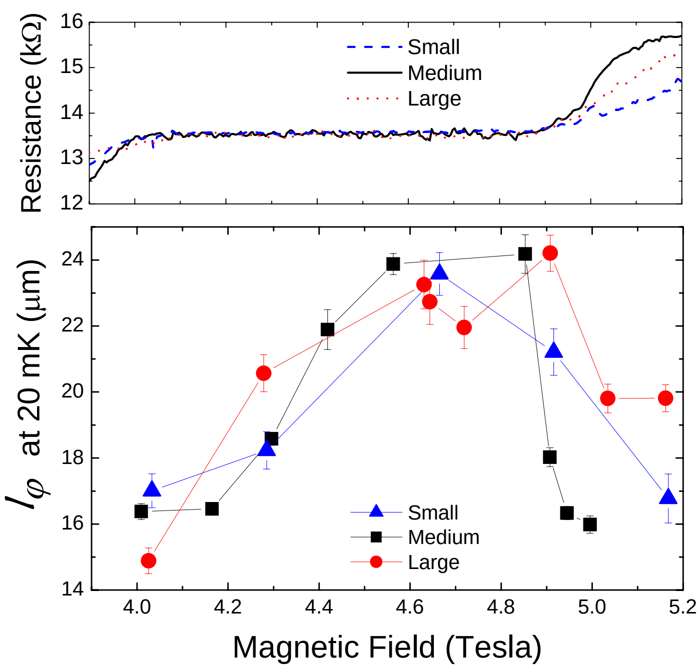
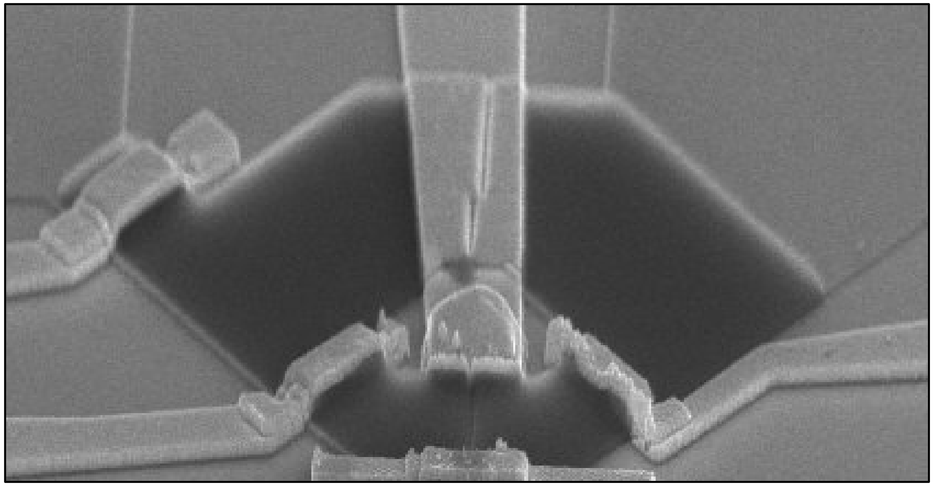
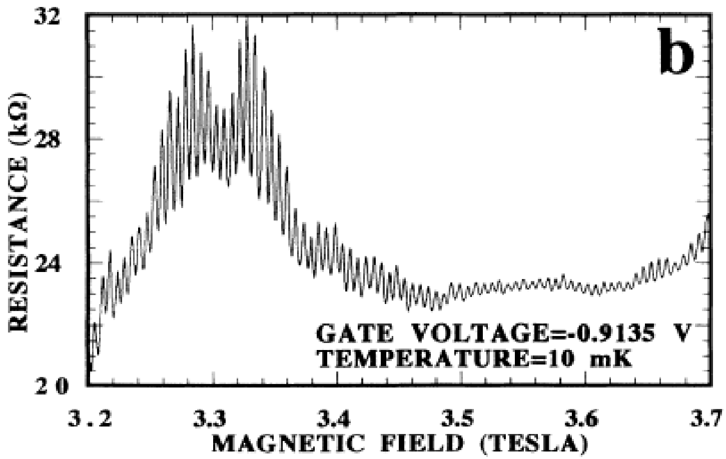
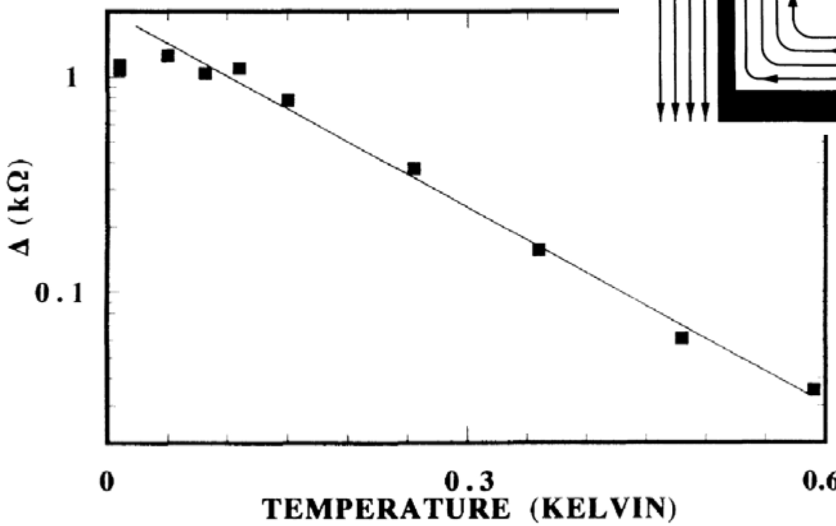


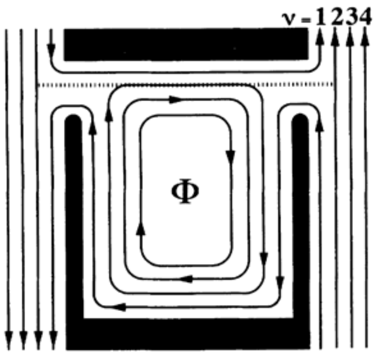


Evidence of $L\varphi$?

In Fabry-Pérot Type interferometer *







Nonetheless, we note that the exponential decay observed here is not necessarily inconsistent with thermal smearing of the single-particle states and point out, for example, that thermal averaging is known to give rise to the (quasi)exponential decay of Shubnikov–de Haas oscillations.[19]

Thermal Smearing ?*

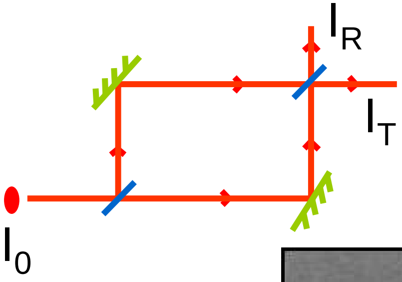
* Bird et al. (PRB 1994)

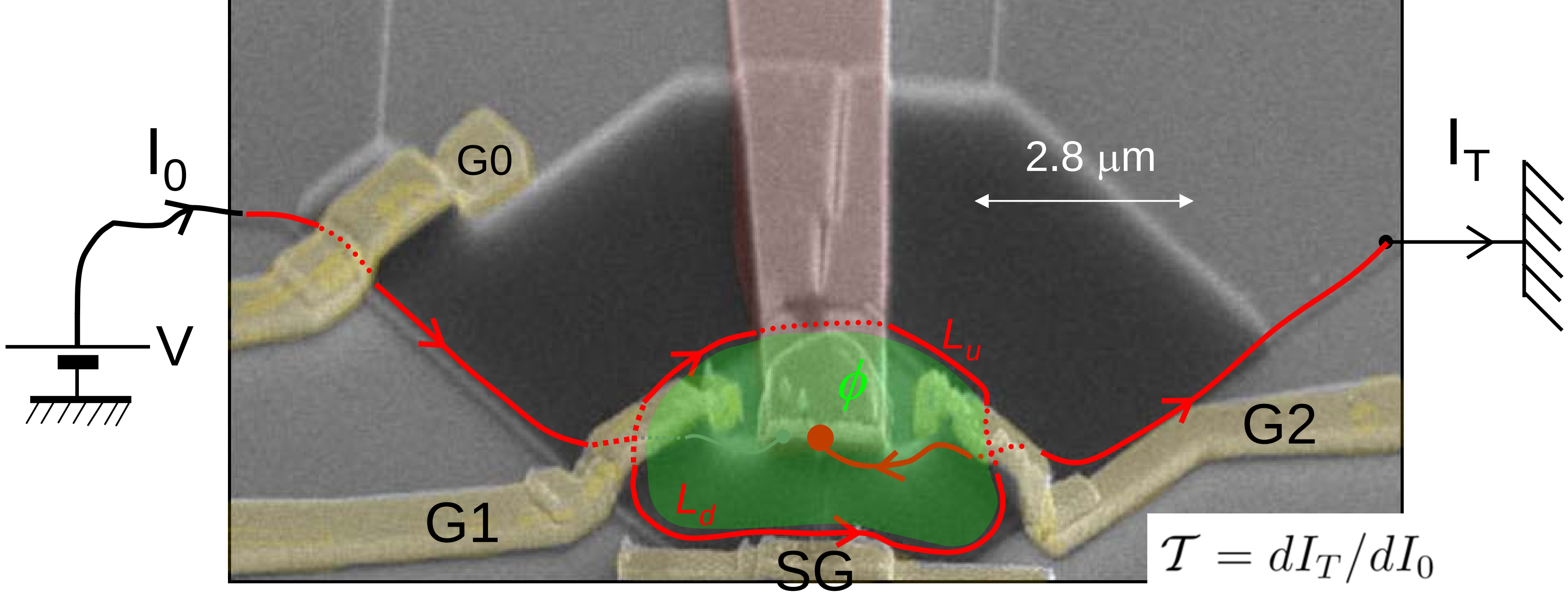
TS always present for Fabry-Pérot type interferometer

OUTLINE

- The electronic Mach-Zehnder (some overlap with the previous talks !!)
- Sample characterization
- Proof of no thermal smearing
- Determination of L_φ
- Conclusion

Filling factor $n_s h/eB = 2$
2 edge states (Chiral 1D wires)
Drift velocity v_D ~10^4 to 10^5 ms^{-1}
B ~ 4 Tesla for $n_S = 2\ 10^{11}$ cm^{-2}





$$\mathcal{T} = dI_T/dI_0$$

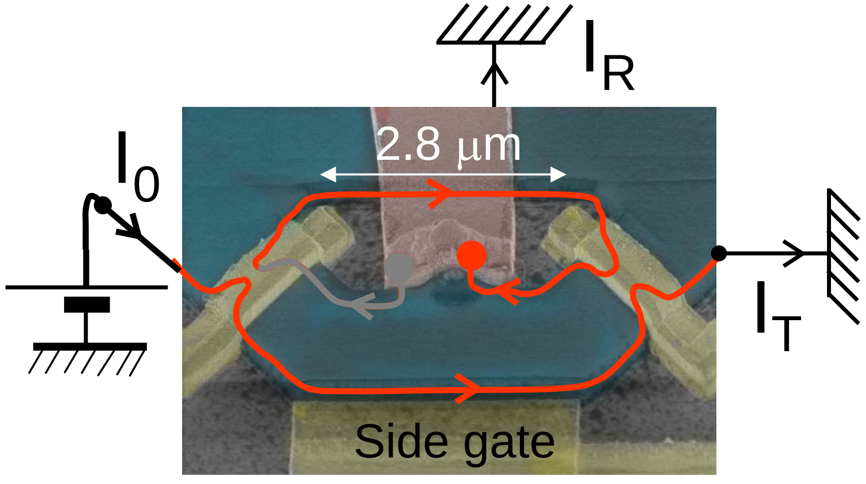
$$\mathcal{T}_1 = \mathcal{T}_2 = 1/2 \qquad \mathcal{T} = 1/2 \times [1 + \mathcal{V} \sin(\phi)]$$

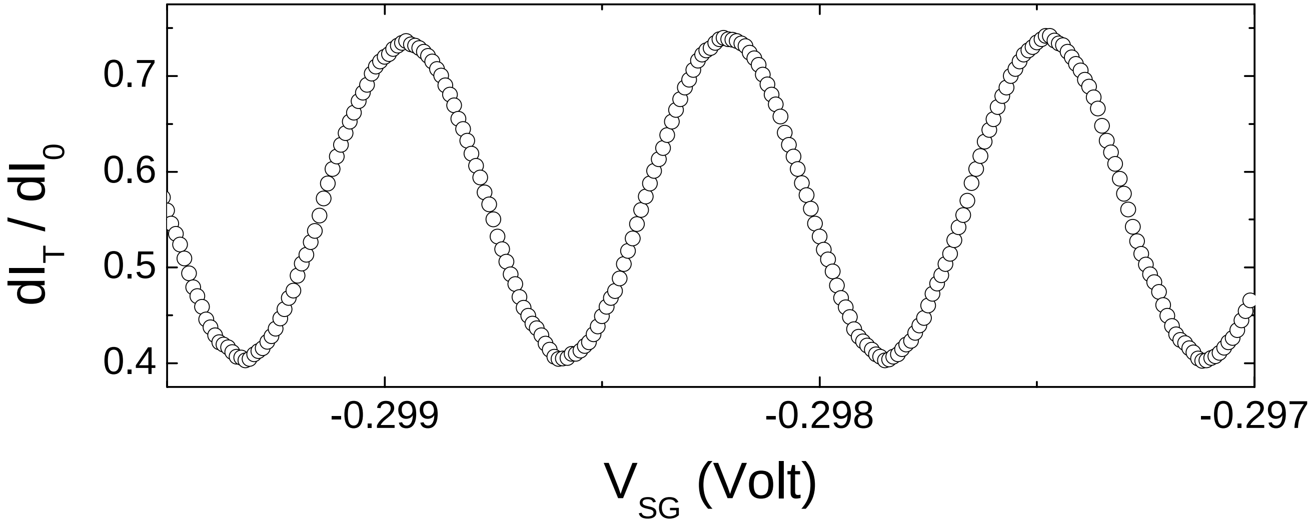
$$\mathcal{V} \propto e^{-2L/L_\varphi} \;;\; L_\varphi(T) \quad ?$$

$$\phi = 2\pi S \times eB/h$$

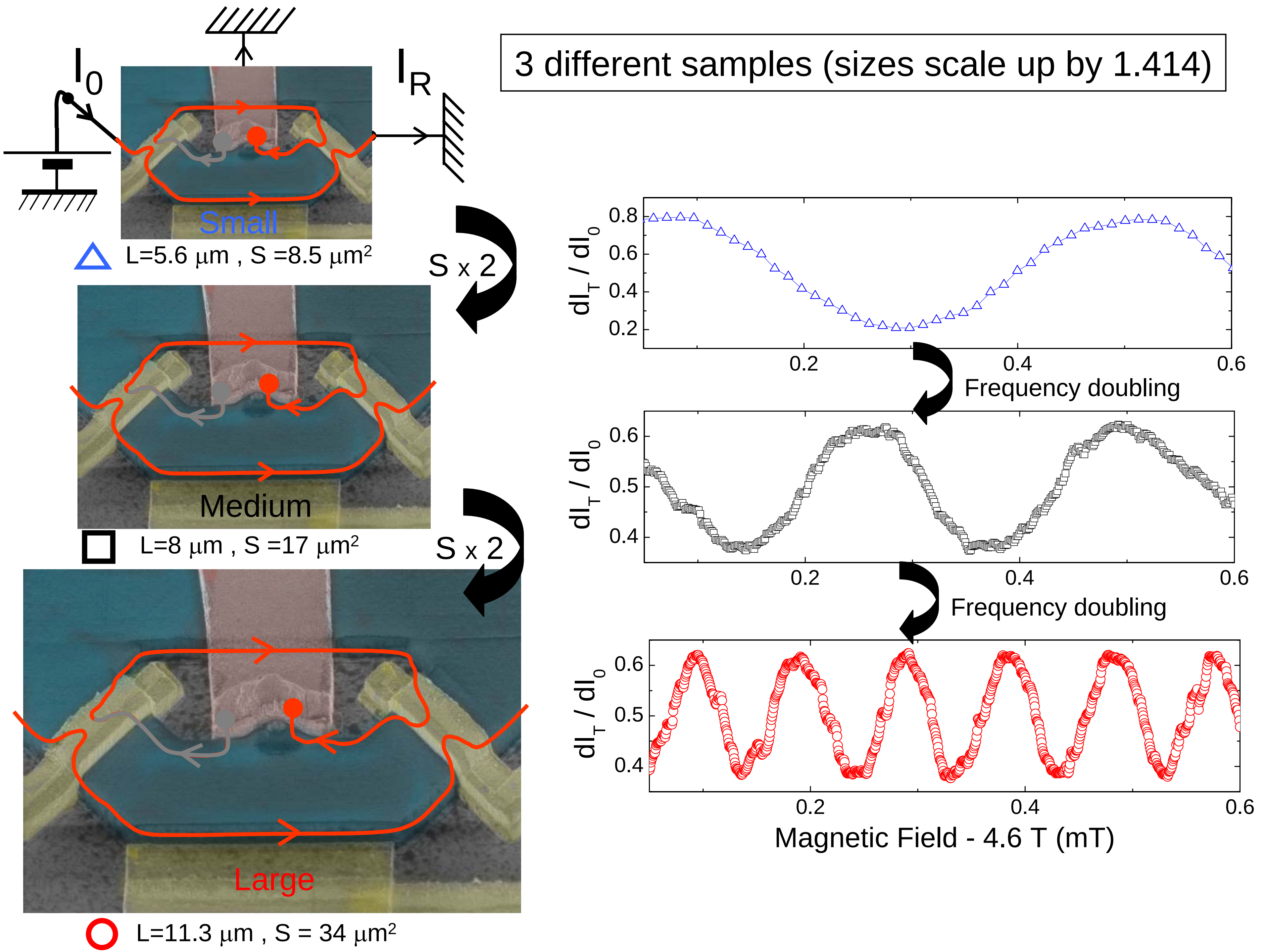
*Note that the inner edge state, fully reflected by all the QPCs, is not represented.

Our samples : up to 65 % visibility at 15 mK



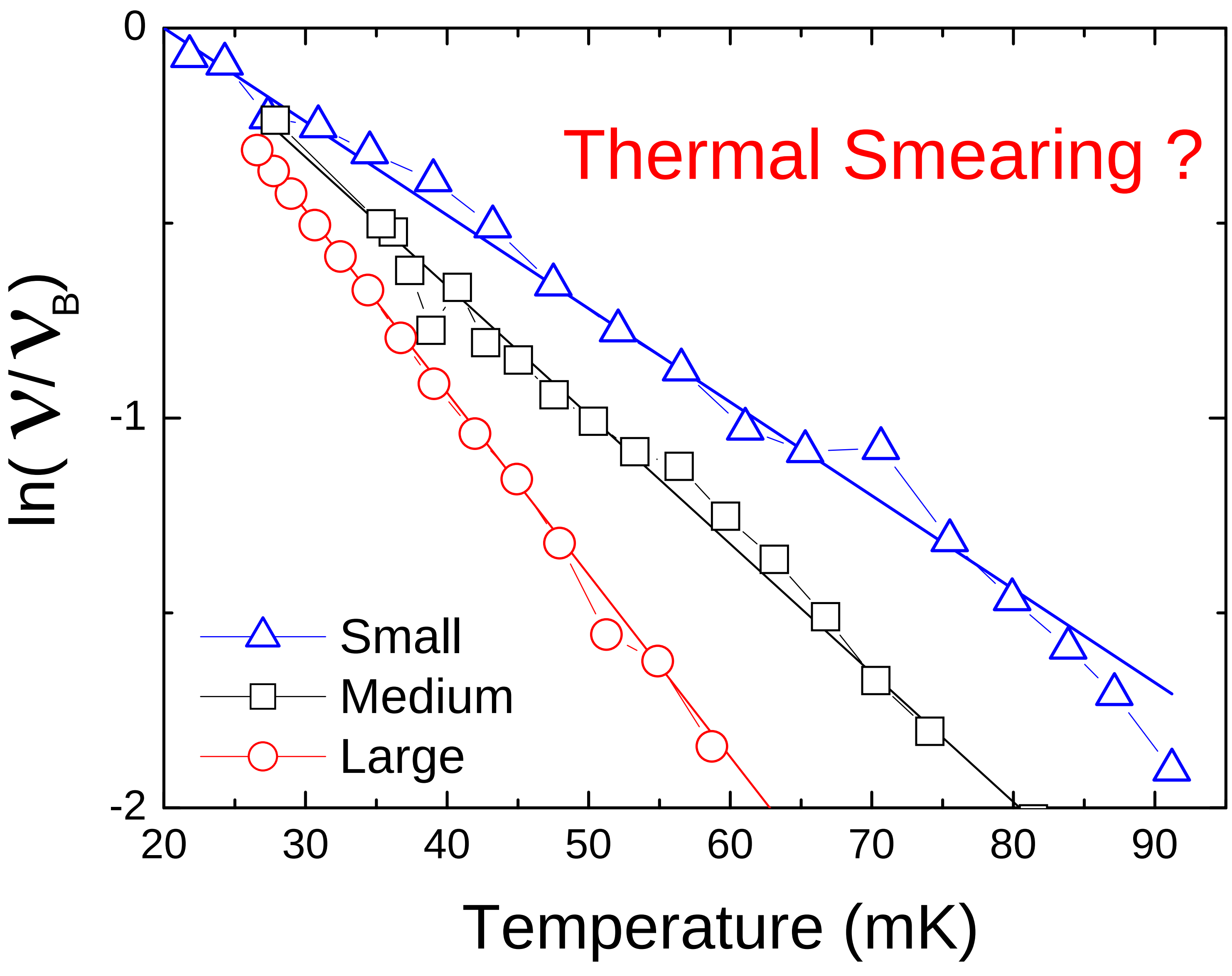


Ji et al. (Nature 2003) – Litvin et al. (PRB 2007) Record : Neder et al. Nature (2007) ~ 90 % @ 10 mK

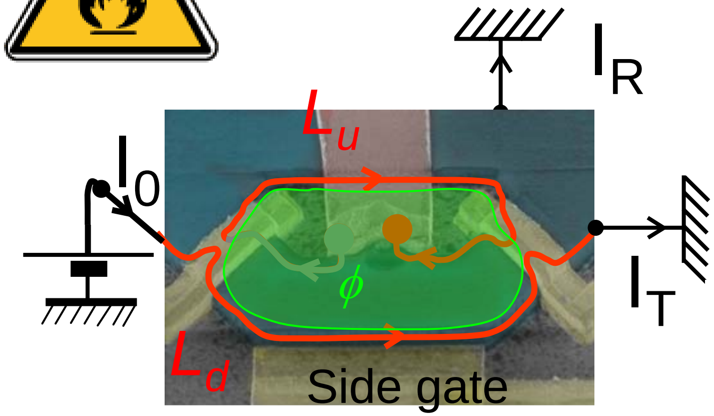


3 different samples (sizes scale up by 1.414)
I0
IR
Small
L=5.6 µm , S =8.5 µm2
S x 2
Medium
L=8 µm , S =17 µm2
S x 2
Large
L=11.3 µm , S = 34 µm2
dIT / dI0
0.8
0.6
0.4
0.2
0.2
0.4
0.6
Frequency doubling
dIT / dI0
0.6
0.5
0.4
0.2
0.4
0.6
Frequency doubling
dIT / dI0
0.6
0.5
0.4
0.2
0.4
0.6
Magnetic Field - 4.6 T (mT)

Temperature dependence



Spurious effect :



Thermal Smearing

$$\mathcal{V} \propto \pi T/(\pi T_S \sinh(\pi T/T_S))$$

$$k_B T_S = \hbar v_D/\Delta L$$

$$\tau(\epsilon) = 1/2 \times [1 + \mathcal{V} \sin(\phi(\epsilon))]$$

$$\phi(\epsilon) = 2\pi S(\epsilon) \times eB/h$$

$$\phi(\epsilon + E_F) = \phi(E_F) + \epsilon \Delta L/(\hbar v_D)$$

One measure

$$\mathcal{T} = dI_T/dI_0$$

$$\mathcal{T}(eV) = \int_{-\infty}^{+\infty} \tau(eV+\epsilon)\frac{df}{d\epsilon}d\epsilon = < \tau(eV) >_{k_B T}$$

Phase averaging over $\Delta\phi \propto T/T_S$

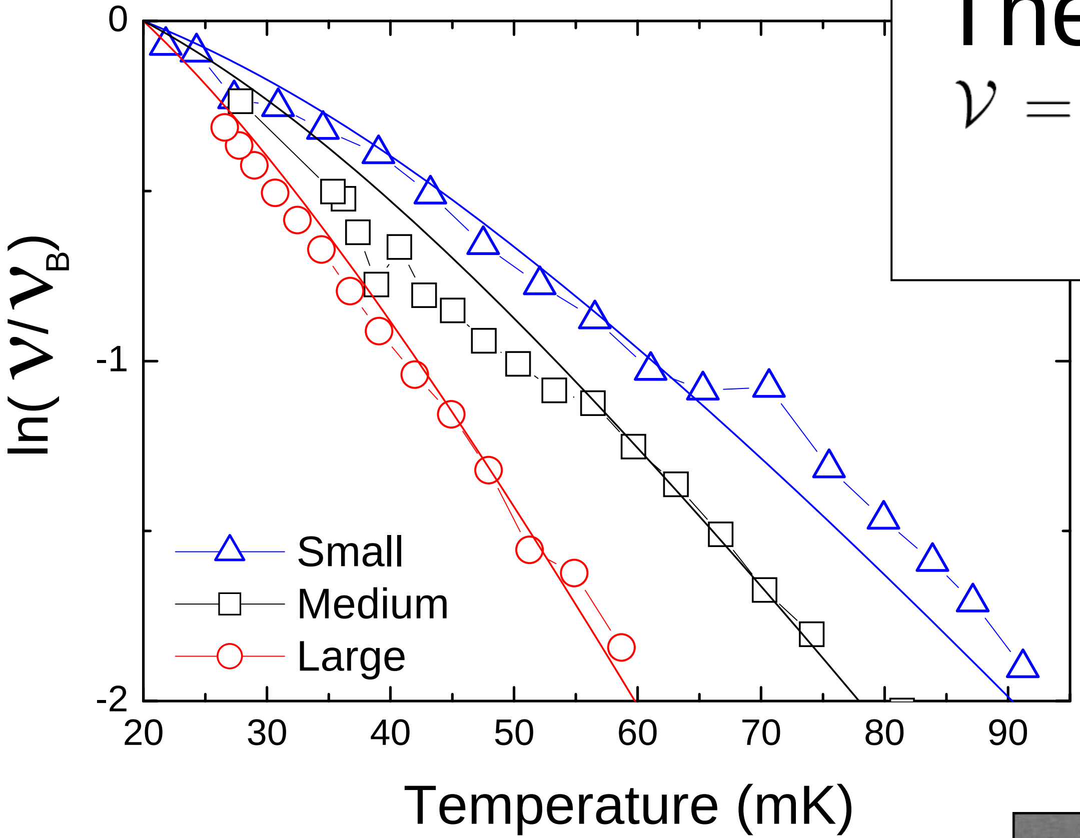
Leads to an ~ exponential decrease of the visibility

V. S.-W Chung, P. Samuelsson and M. Büttiker (PRB 2005)

Thermal Smearing

$$\mathcal{V} = \mathcal{V}_0 \pi T / (T_S \sinh(\pi T / T_S))$$

$$k_B T_S = \hbar v_D / \Delta L$$

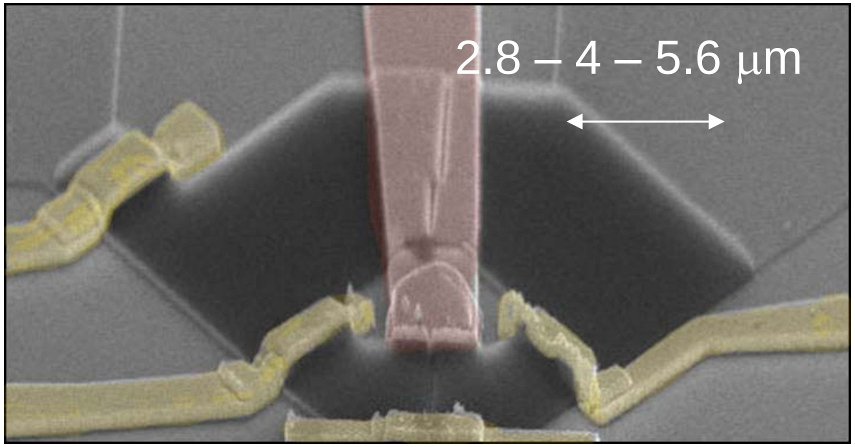


Fits with Thermal Smearing give :
T_S = 66, 56 , 41 mK

$v_D \sim 5\ 10^4\ ms^{-1}$

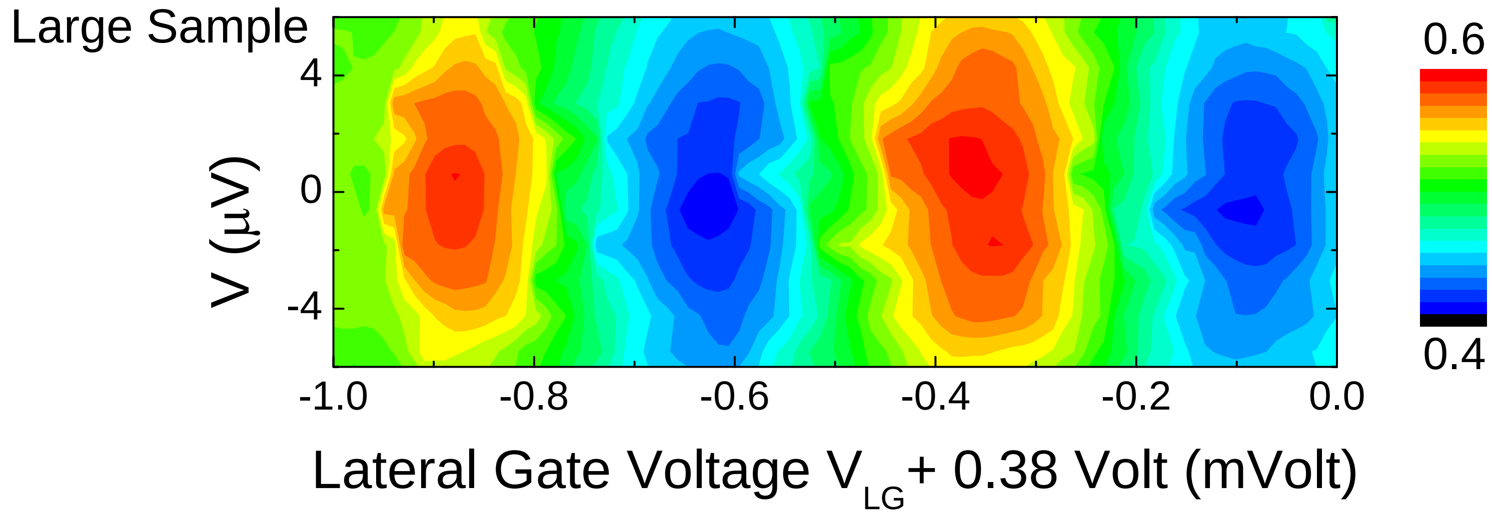
$\Delta L \sim 5$, 6 , 8 μm from Small to Large ?

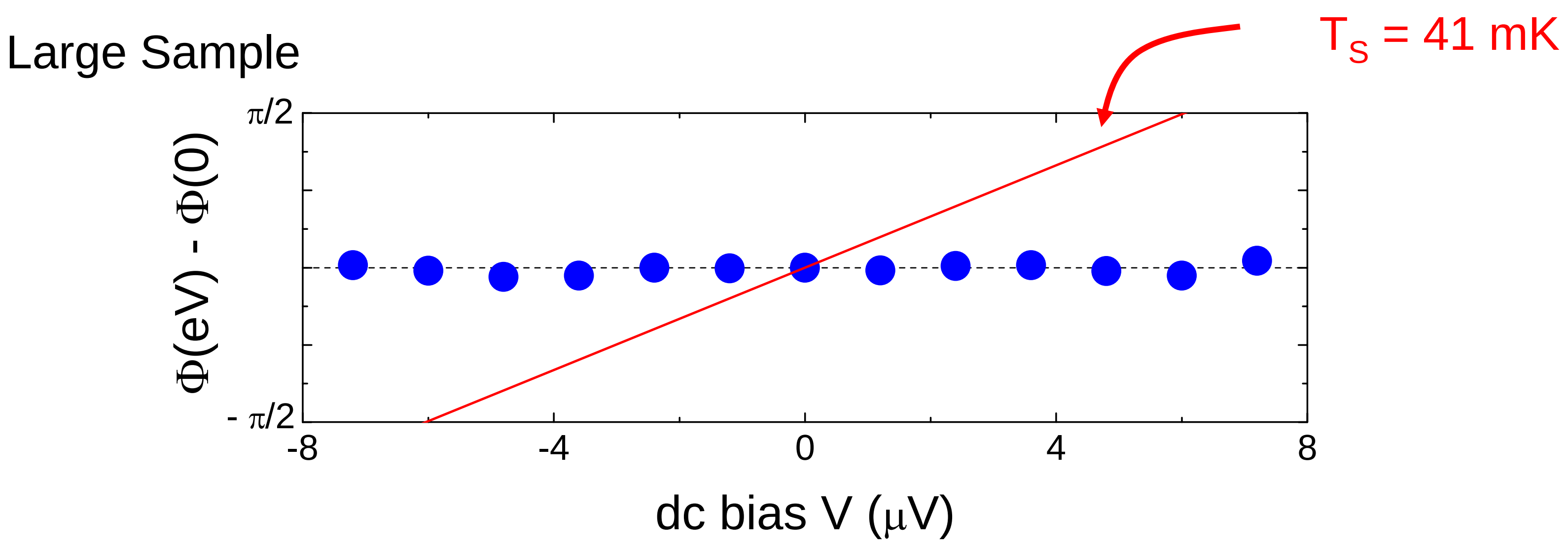
Not compatible with
the lithography precision !



Proof for non Thermal Smearing in our samples

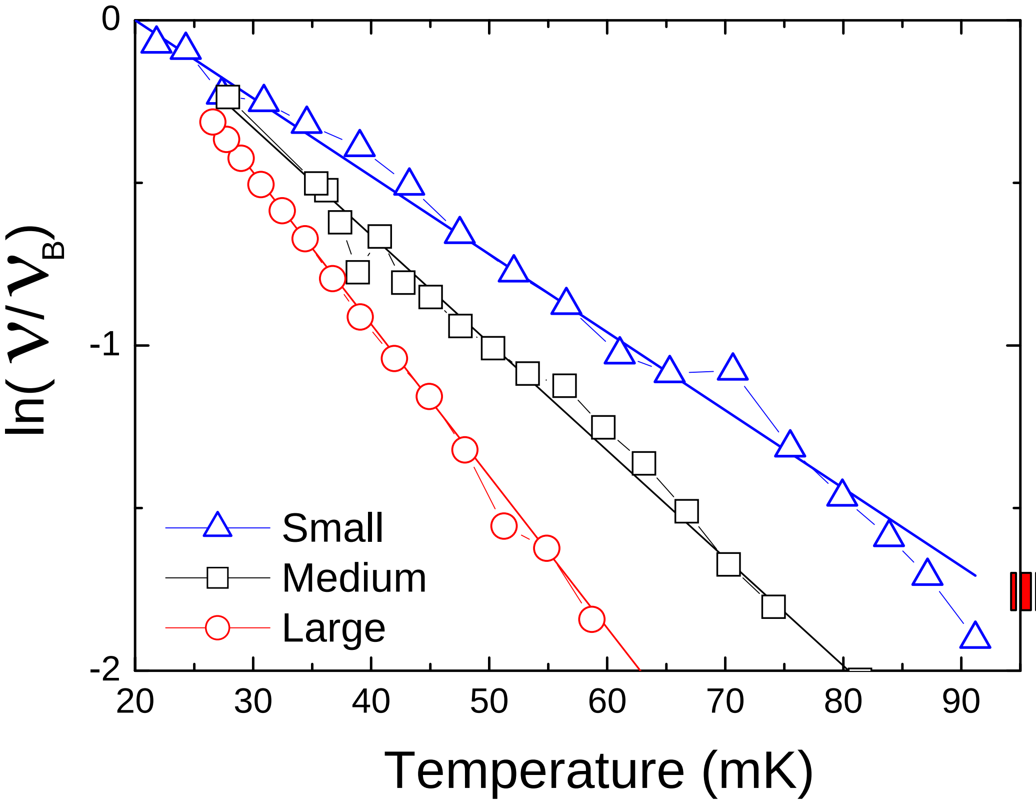
$$\mathcal{T}(eV) \propto 1 + \mathcal{V}(eV)\sin(<\phi(eV)>_{k_BT})$$

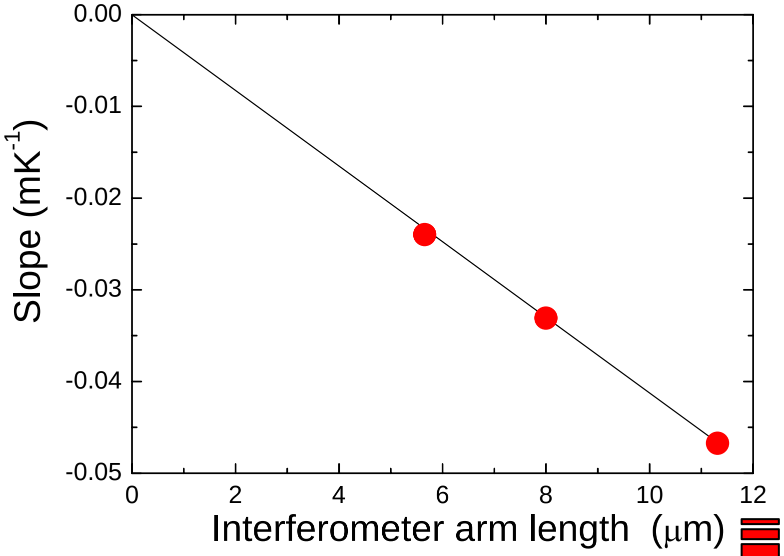




Phase rigidity checked for the 3 studied samples !

Temperature dependence





$$\nu \propto e^{-2L/L_\varphi}$$

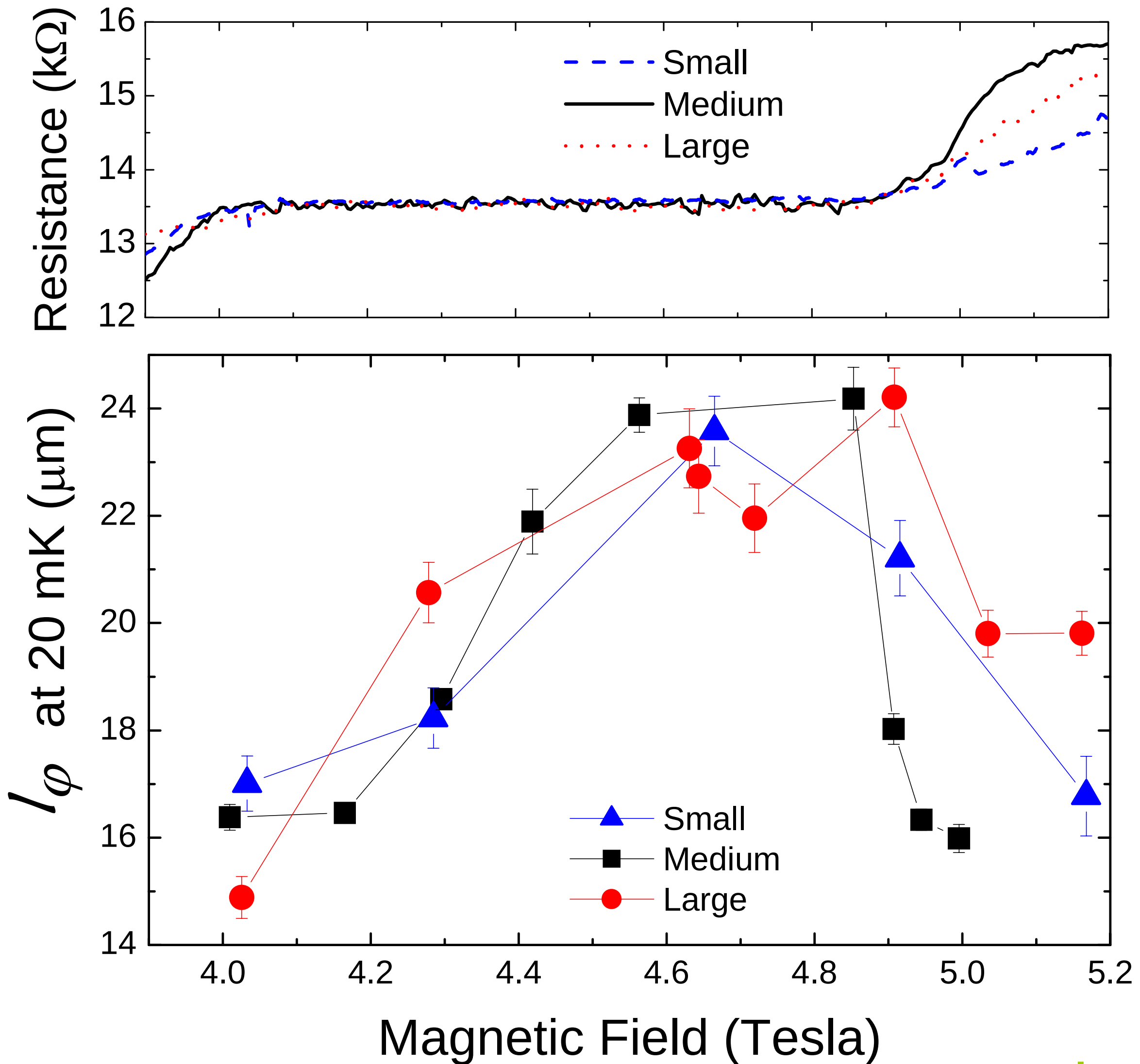
$$L_\varphi(T) \propto T^{-1}$$

$L\varphi$ = 22 μm at 20 mK

$\nu \sim \exp[-T/T_\varphi(L)] = \exp[-2L/L_\varphi]$

$L_\varphi = 2L T_\varphi(L)/T_B$

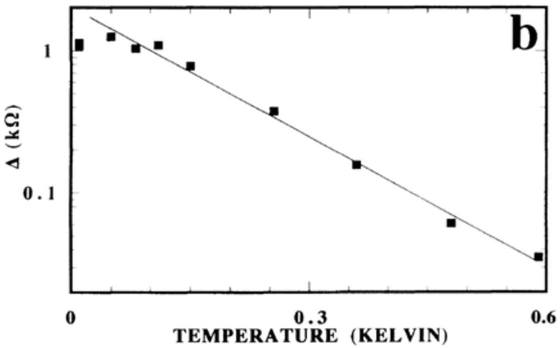
Magnetic Field dependence



$L\varphi = 2LT\varphi(L)/T_B$

$T_B = 20$ mK

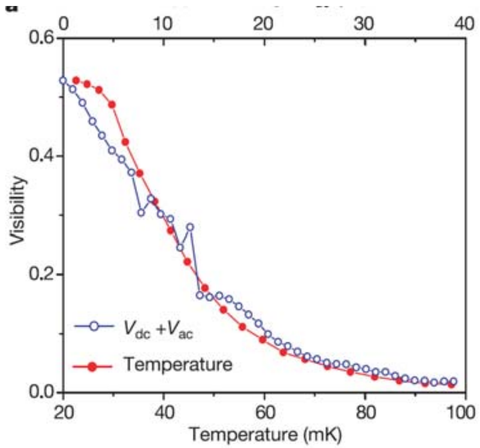
Universality of $L\varphi$?



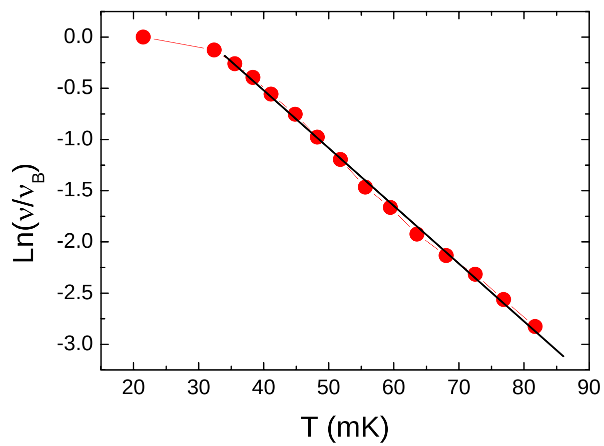
* Bird et al. (PRB 1994)

Slope ~ 7 K^{-1}
sample size ~ 1 μm
~ same $L\varphi$

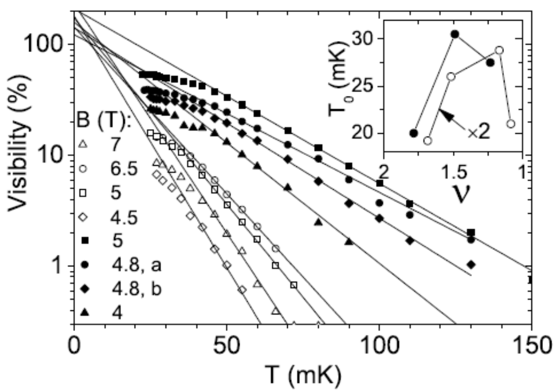
But mixing of thermal smearing and finite $L\varphi$



Ji et al. (Nature 03)



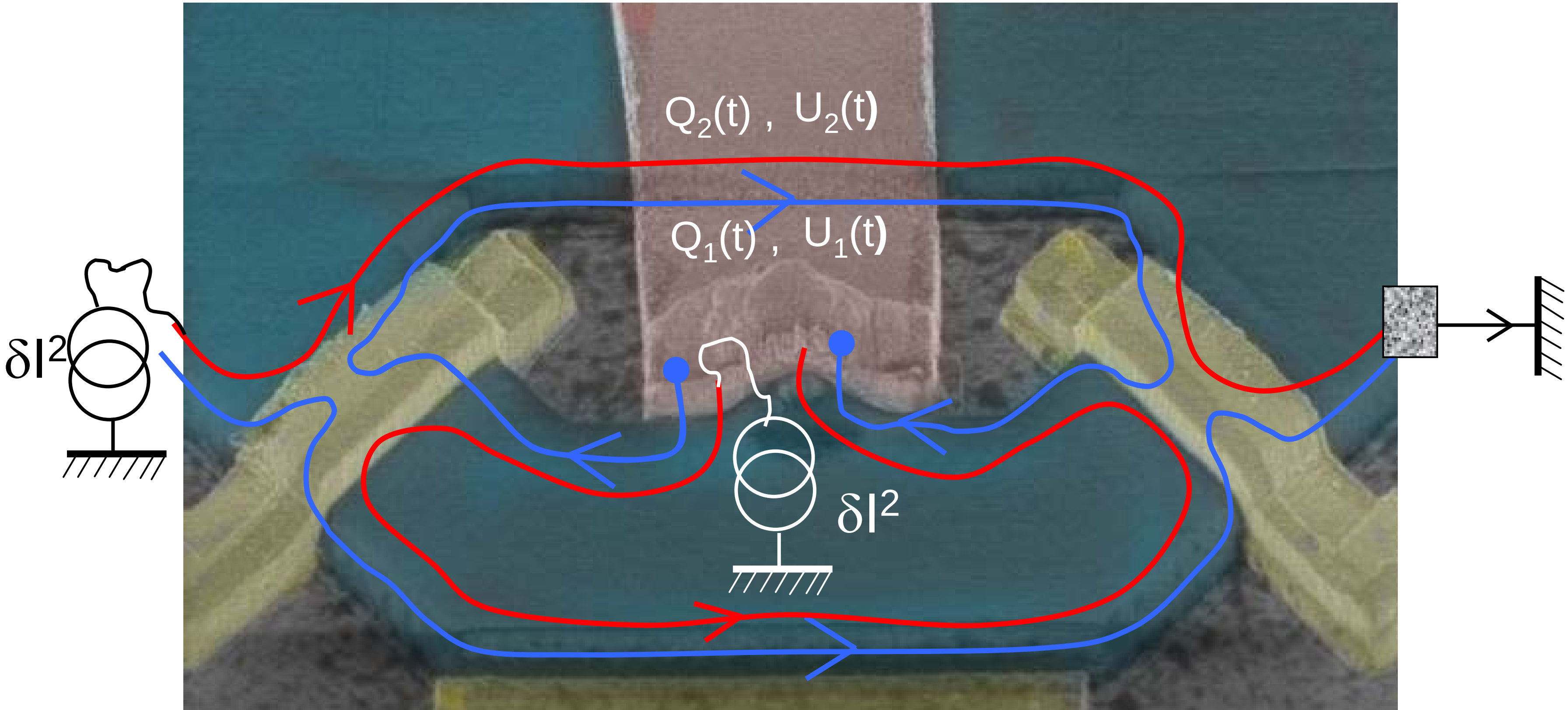
Slope 56 K^{-1}
same sample size
(L ~ 10 μm)
~ same $L\varphi$



* Litvin et al. (arXiv:0802.1164)

~ same $L\varphi$
but
maximum @ filling factor 1.5

Decoherence generated by Johnson-Nyquist Noise



$$\delta\varphi(t) = \frac{1}{\hbar}\int_t^{t+\tau} e{U_1(t)}dt$$

$$\tau = L/v_D$$

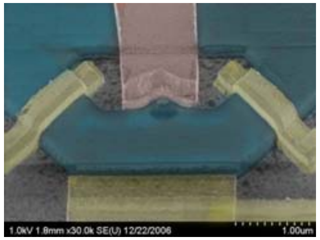
$$\delta I^2 \longrightarrow \delta Q_2^2 \longrightarrow \delta Q_1^2 \longrightarrow \delta U_1^2 \longrightarrow \delta\varphi^2$$

$$\delta I^2 = 4k_B G_Q T \Delta\nu \longrightarrow \mathcal{T} \propto [1 + \mathcal{V}_0 \sin(<\varphi>)e^{-<\delta\varphi^2>/2}]$$

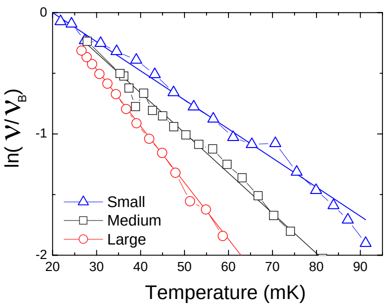
* Seelig and Buttiker (PRB 2001)

P. Roulleau et al. arXiv:0802.2219

Conclusion



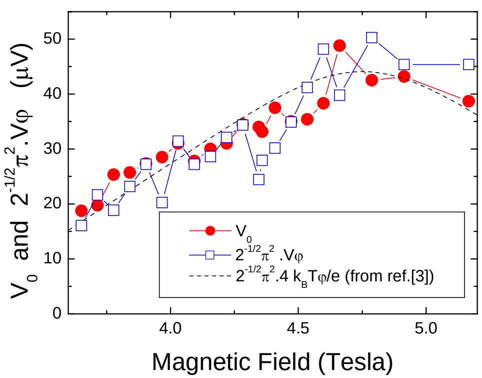
High visibility Mach-Zehnder Interferometer. Up to 65 % @ 15 mK on the Hall plateau at $\nu = 2$



Exponential decrease of ν with temperature

Scaling with the sample size

$$L_\varphi(T) \propto T^{-1}$$



- Finite L_φ arises from Johnson-Nyquist Noise in the neighboring edge state

- B change the coupling between edge states

See Poster Session : P. Roulleau et al. (PQHE04)

P. Roulleau et al. PRB 76, R161309 (2007)
P. Roulleau et al. arXiv:0710.2806 (PRL 2008)
P. Roulleau et al. arXiv:0802.2219