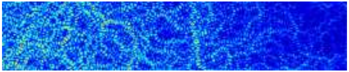
Broadband Transmission Enhancement Through Opaque Barriers with Symmetric Diffusive Slabs

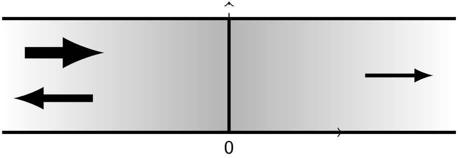
Elie Chéron, Simon Félix, Vincent Pagneux

LAUM, CNRS, Le Mans Université, France



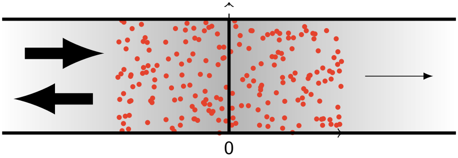
Introduction

barrier
alone

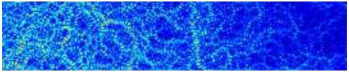


low
transmission

barrier
+
disorder



lower
transmission

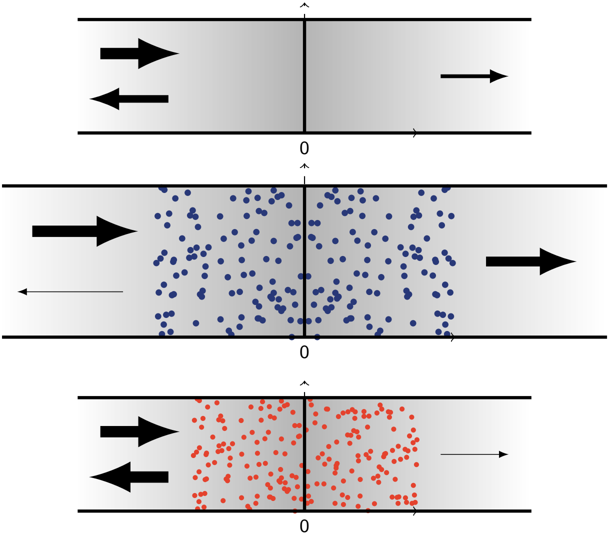


Introduction

barrier alone

barrier + symmetric disorder

barrier + disorder



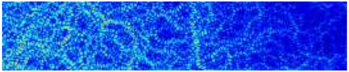
low transmission

enhanced transmission

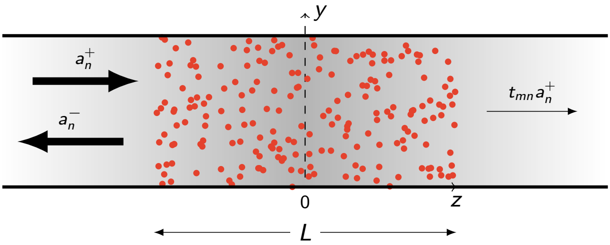
(broadband, each single realization)

lower transmission

E. Chéron, S. Félix, V.P.. Phys. Rev. Lett. 122, 125501 (2019)



Transport regimes



Helmholtz equation

$$\left(\nabla^2 + k^2\right)\psi(\vec{r}) = 0$$

+ Boundary Conditions

$$k = k_0\left(1 + \delta(z, y)\right)$$

Diffusive regime

$1 < g < N$

$\ell < L$

N propagating modes

$$\psi(z, y) = \sum_n a_n(z)\phi_n(y)$$

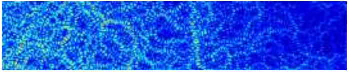
Transmission Matrix

$$T = t_{mn}$$

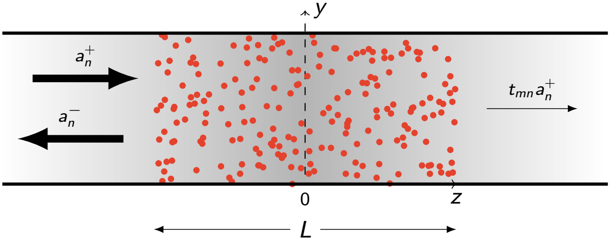
Conductance

$$g = \sum_{nm} \mid t_{nm} \mid^2 = \mathrm{Tr}(TT^\dagger)$$

$$g = \sum_n \tau_n$$



Transport regimes



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$\ell < L$

Properties :

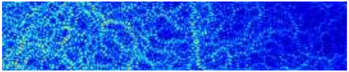
Derived by Dorokhov (1982)
Mello, Pereyra, Kumar (1988)

- Conductance fluctuations
- Bimodal distribution of τ_n:
- ...

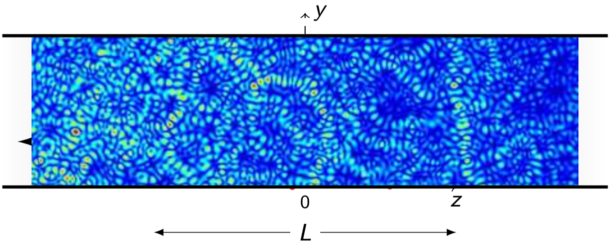
Ohm's Law

$$g = \frac{\pi}{2}\frac{N\ell}{L + \frac{\pi}{2}\ell}$$

For $L >> \ell$ $\quad g \propto \frac{1}{L}$



Transport regimes



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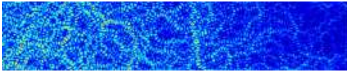

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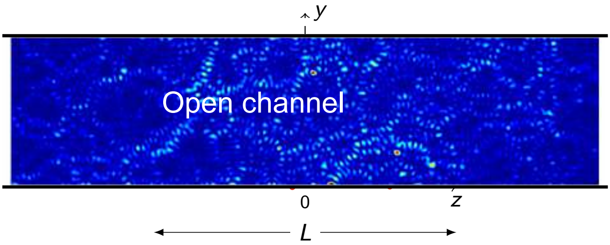

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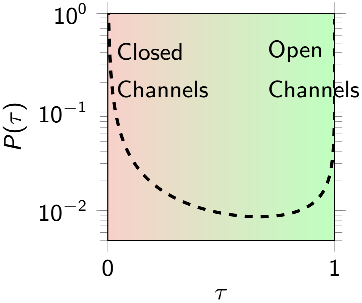


Singular Value Decomposition of the transmission matrix :

$$T = U \Lambda V^\dagger$$

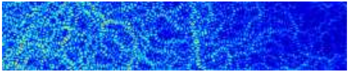
Λ : Diagonal matrix of eigenvalues $\sqrt{\tau_n}$

U : Input eigenchannels

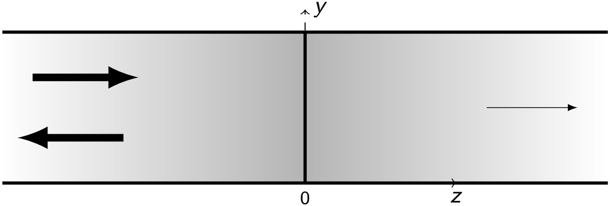
V : Output eigenchannels

Going back to the

Broadband Transmission Enhancement Through Symmetric Diffusive Disordered Slabs



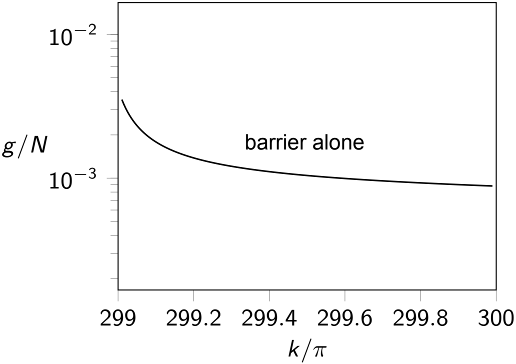
Broadband Enhancement

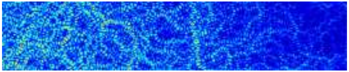


Parameters :

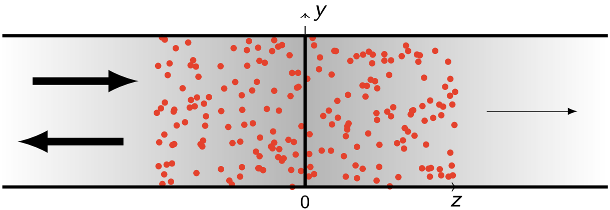
$N = 300$

$(N-1)\pi < k < N\pi$

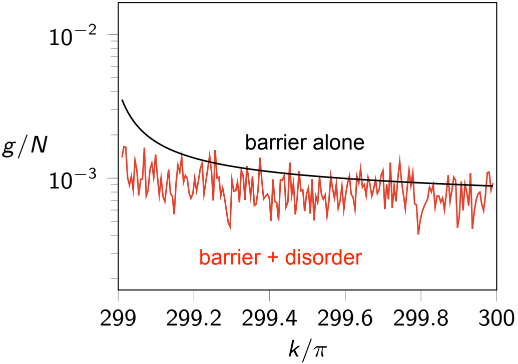




Broadband Enhancement



Disorder

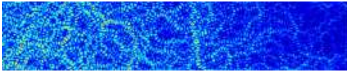


Parameters :

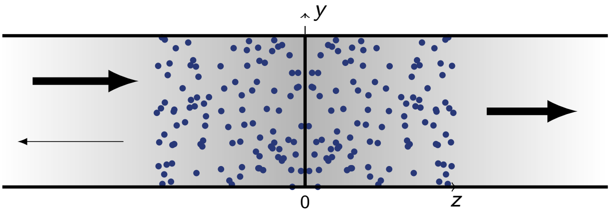
$N = 300$

$\ell = 0.089$

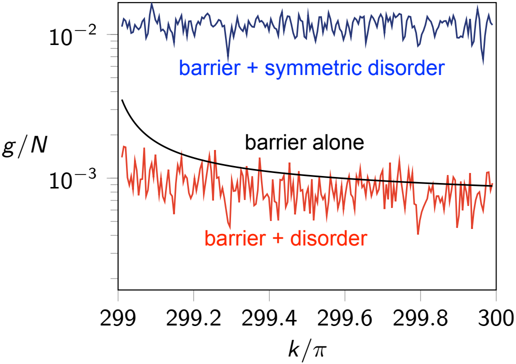
$(N-1)\pi < k < N\pi$



Broadband Enhancement



Symmetric Disorder



Parameters :

$N = 300$

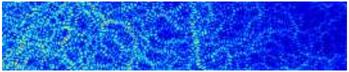
$\ell = 0.089$

$(N-1)\pi < k < N\pi$

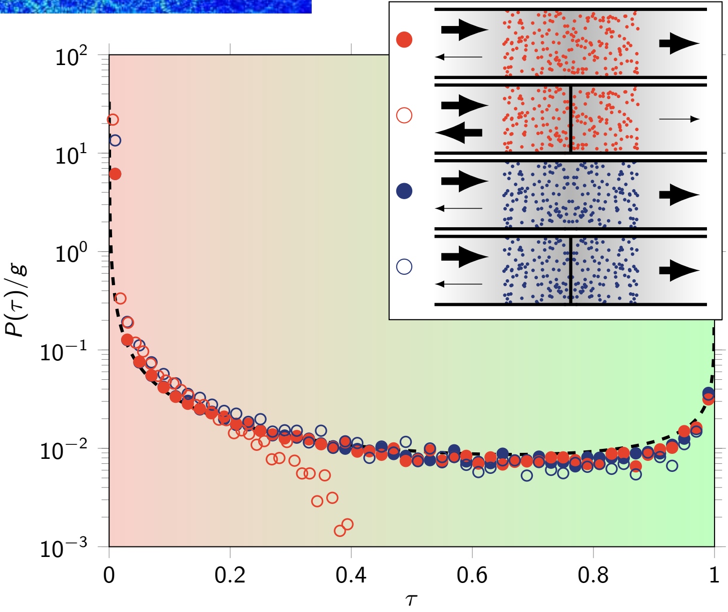
- Enhancement $>$ x15
- Broadband
- Single realization

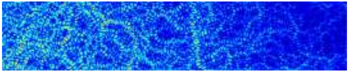
Characterization of the

Broadband Transmission Enhancement Through Symmetric Diffusive Disordered Slabs

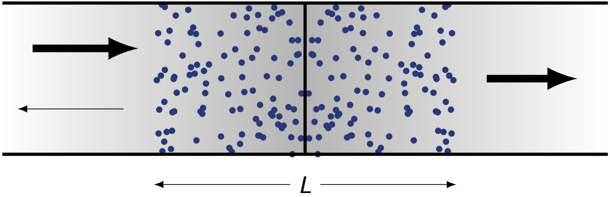


Eigenvalue distribution



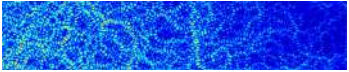


Is it Tunable ?



Depends on L

… and depends on the barrier strength



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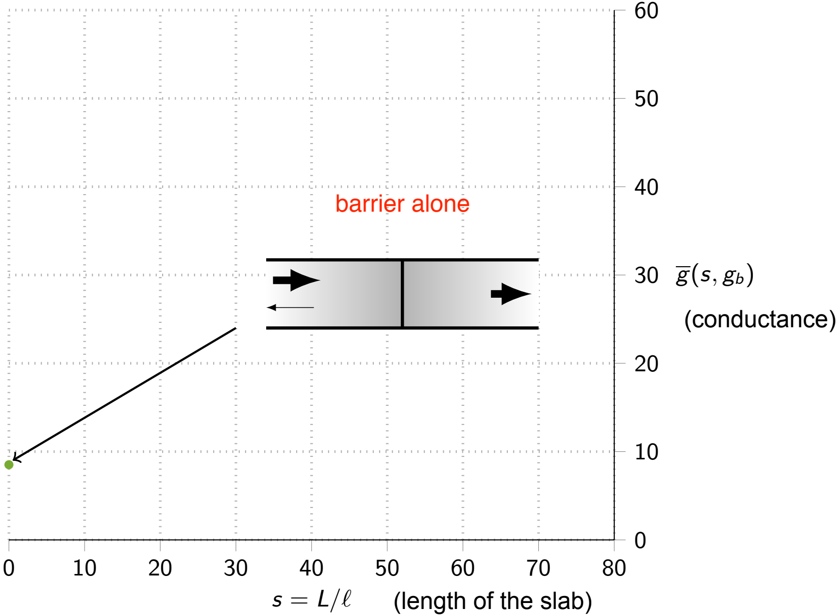

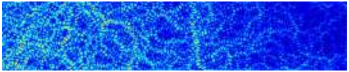

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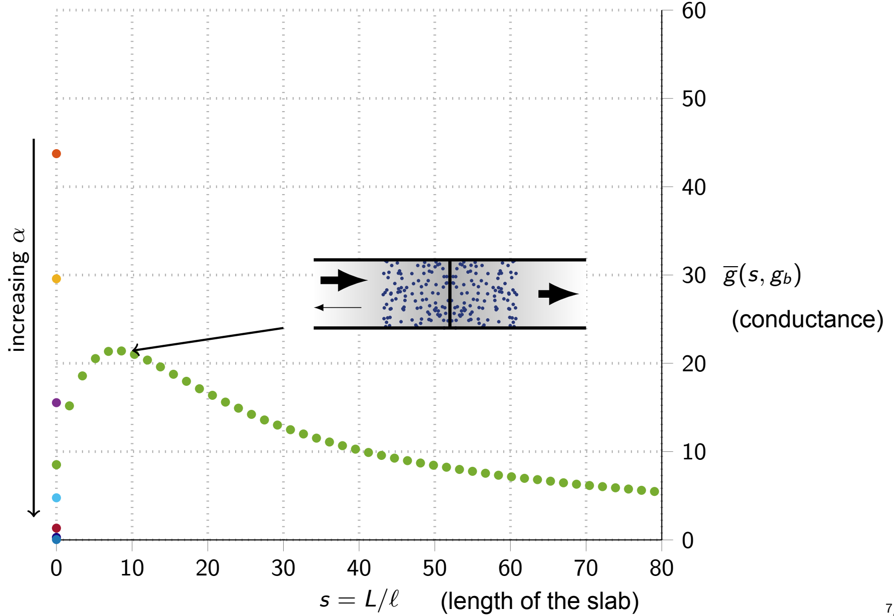

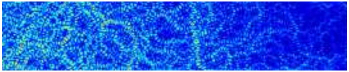

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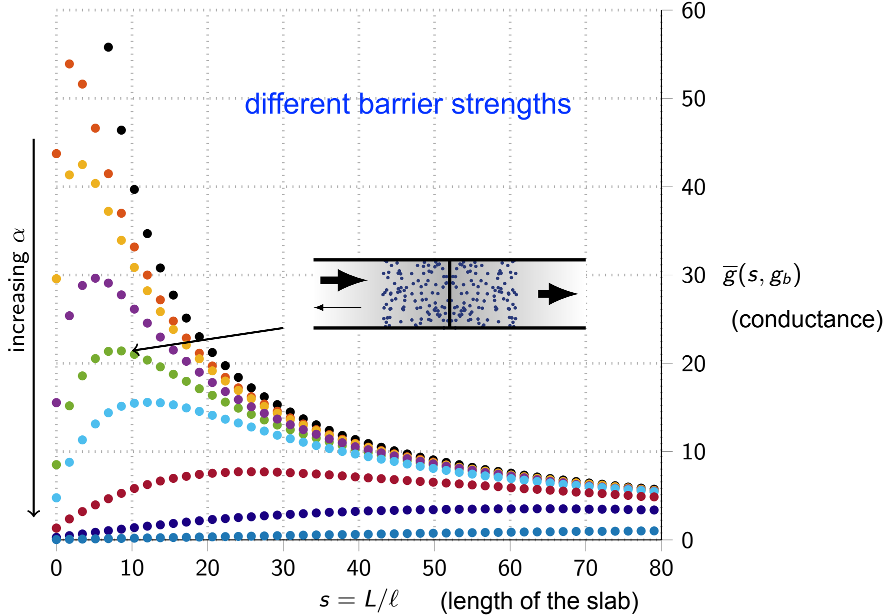

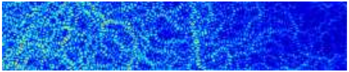

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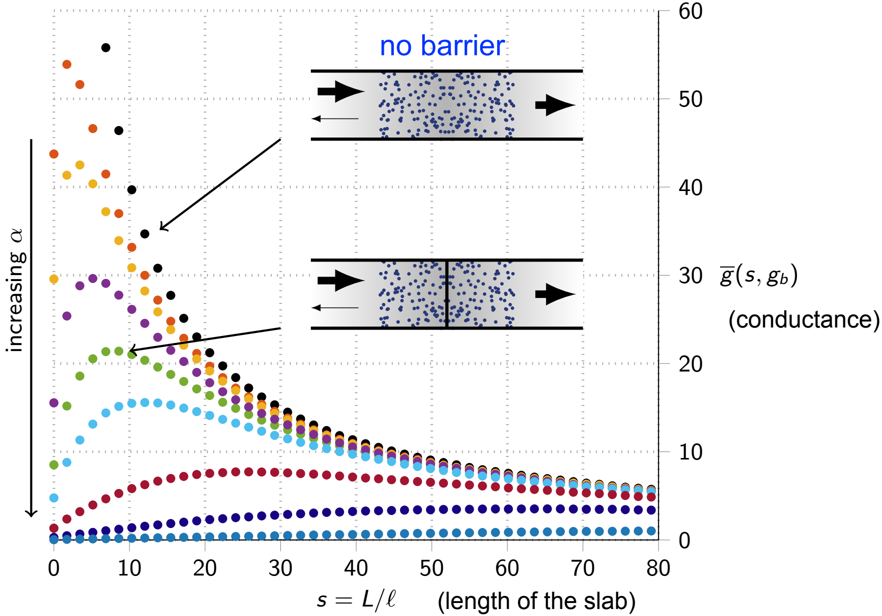

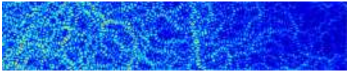

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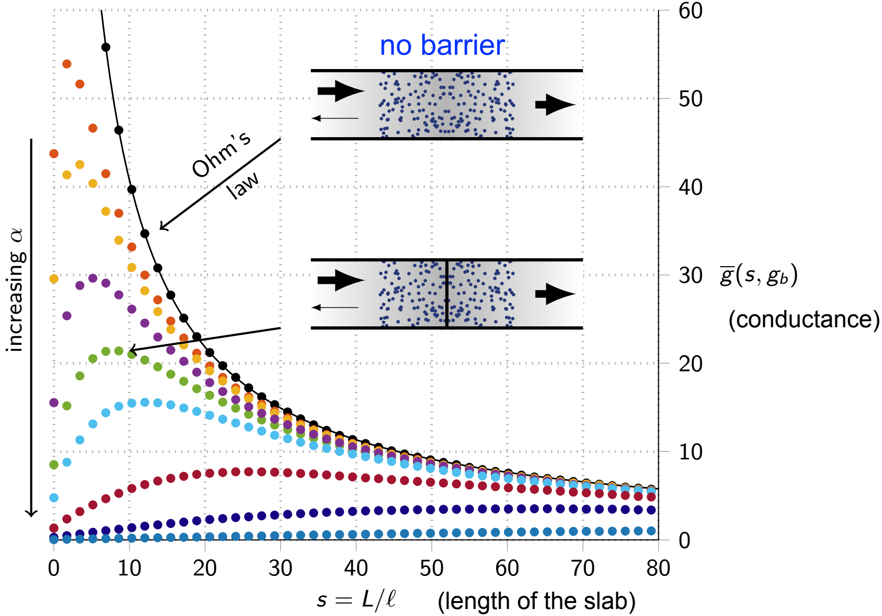
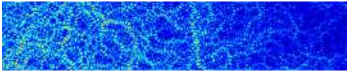




barrier in quantum dots (no disorder)

R.S. Whitney, P. Marconcini, M. Macucci
Phys. Rev. Lett. 102, 186802 (2009)

Whitney's model:

$$\overline{g}(s, g_b) = \frac{\zeta_1(s) g_b}{1 + \zeta_2(s) g_b}$$

2 functions depending on s

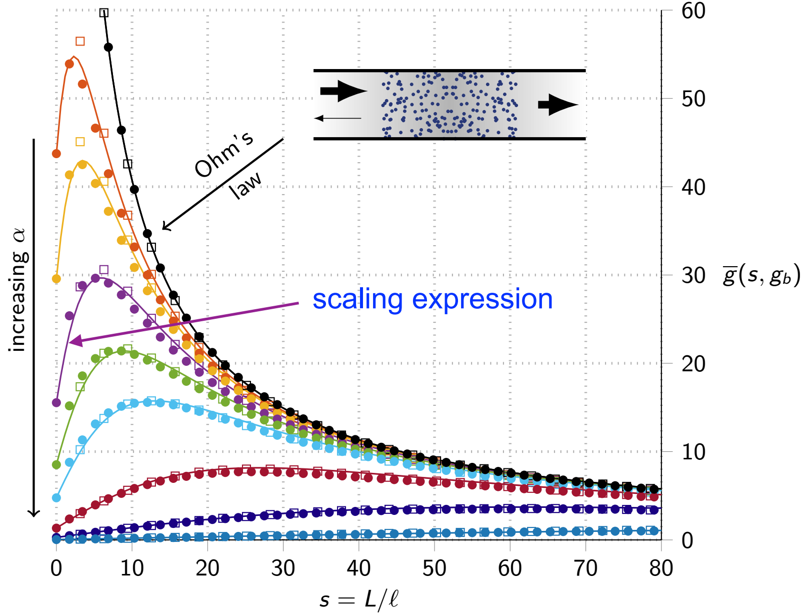
Conductance of the barrier

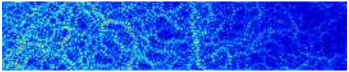
Finally:

$$\overline{g}(s, g_b) = \frac{g_D}{1 + (1 - g_b/N)\dfrac{g_D(s)}{(1 + 0.4s) g_b}}$$

scaling expression

Is it Tunable ?





A simple model :

Conductance expression :

$$\overline{g}(s, g_b) = \frac{g_D}{1 + (1 - g_b/N)\dfrac{g_D(s)}{(1+0.4s)g_b}}$$

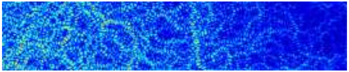
Optimisation :

$$s_{\max} = \frac{1}{0.8}\left(\sqrt{0.8\pi}\sqrt{N/g_b - 1} - 2\right)$$

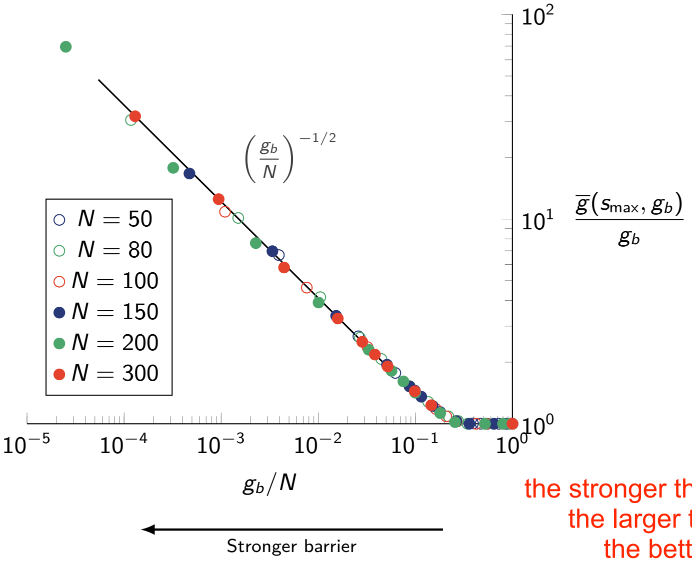
For large barrier contrast :

$$\overline{g}(s_{\max}, g_b) \simeq \frac{g_D}{2}$$

$$\frac{\overline{g}(s_{\max}, g_b)}{g_b} \propto \left(\frac{g_b}{N}\right)^{-1/2}$$

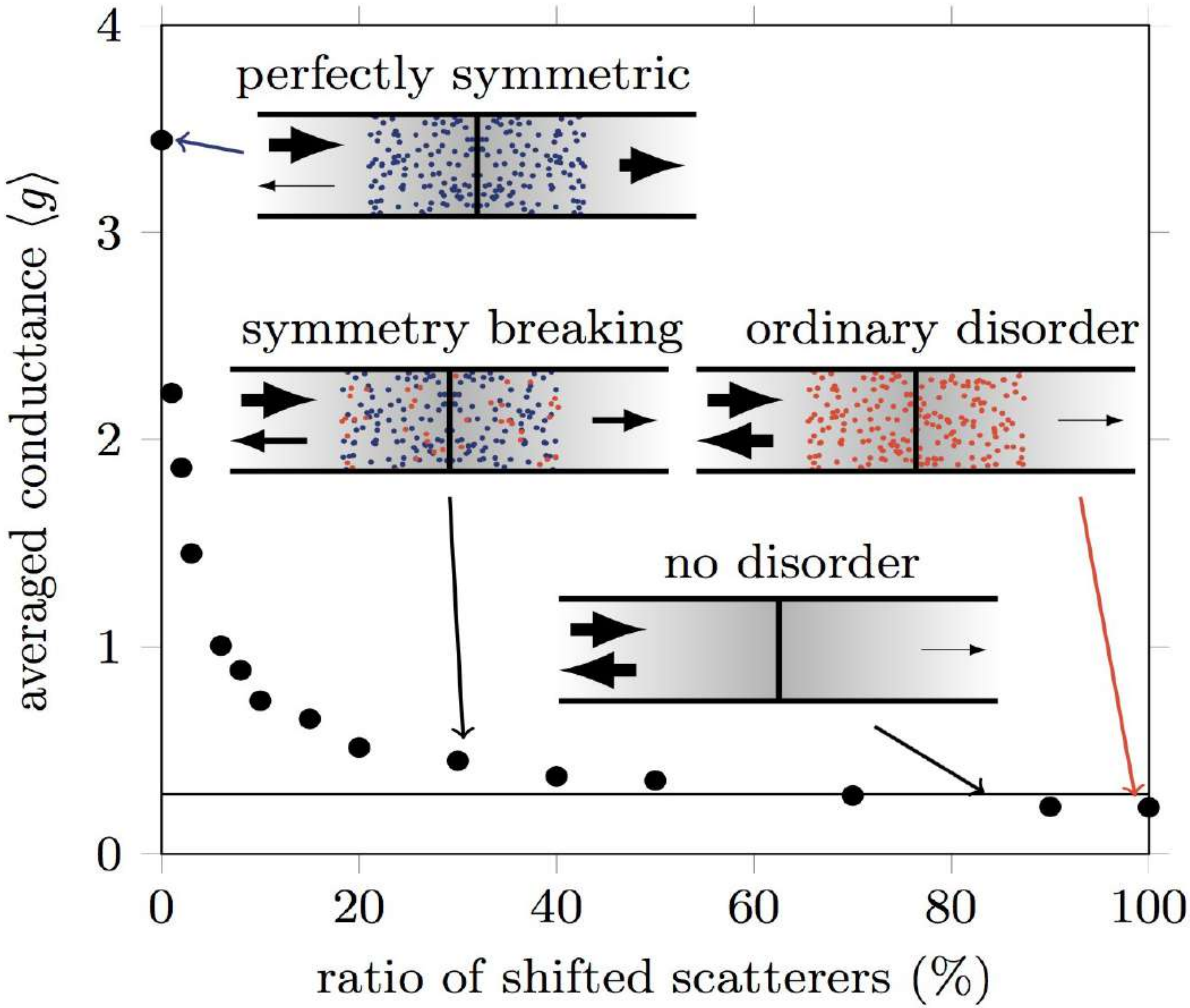


Scaling



the stronger the barrier
the larger the N
the better

Effect of symmetry breaking / Defects



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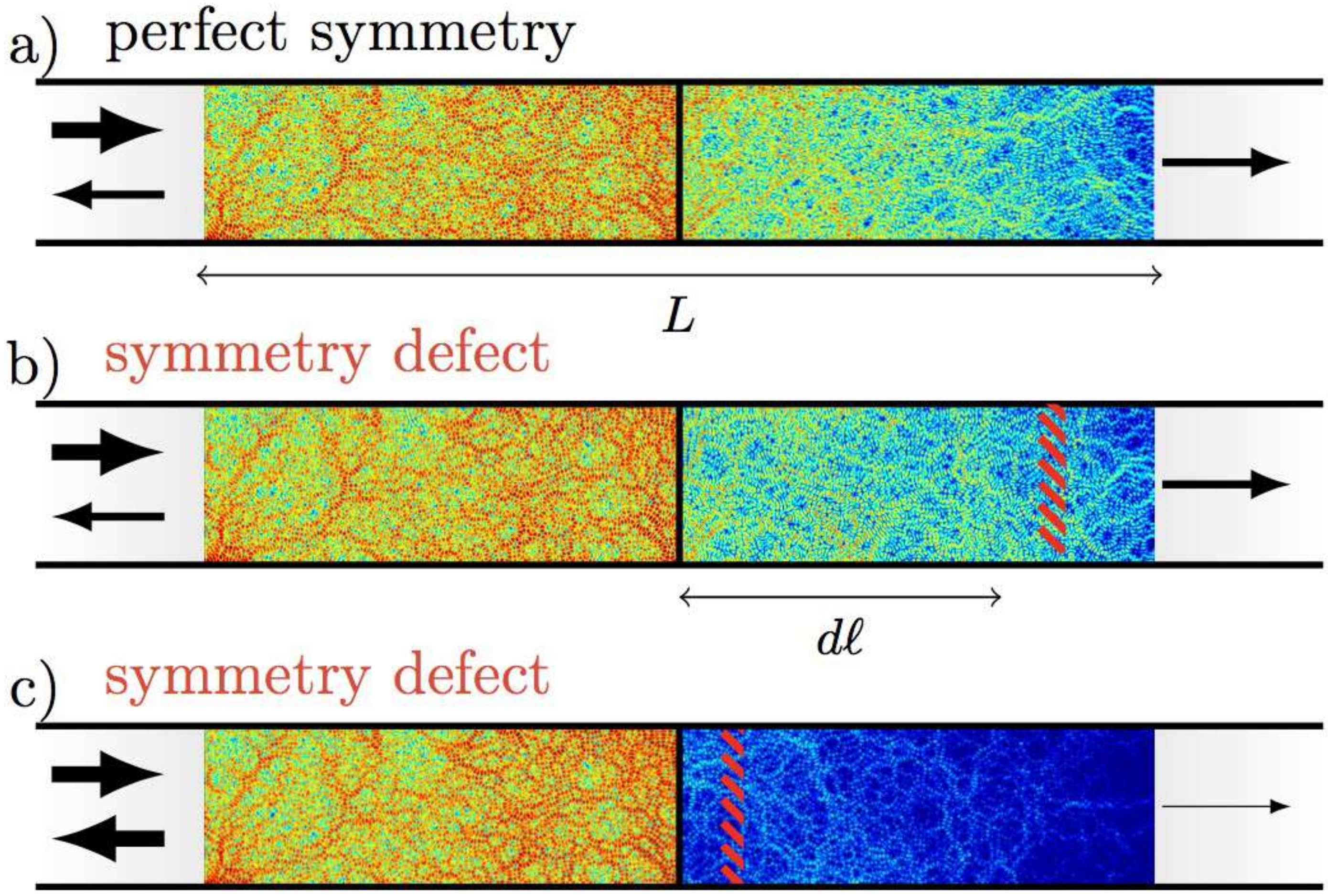

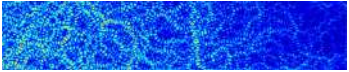

Conclusion

Opaque barrier + Symmetric disordered media

- Broadband conductance enhancement
- Tunable regarding to the scale parameter
- No averaging (it works on one single realization)

Not so much sensitive to loss
$\Rightarrow$ Experimental

more details in

E. Chéron, S. Félix, V.P.. Phys. Rev. Lett. 122, 125501 (2019)