Anne Anthore : enseignante-chercheuse

Université de Paris

since 2005 : MCF
since 2021 : prof

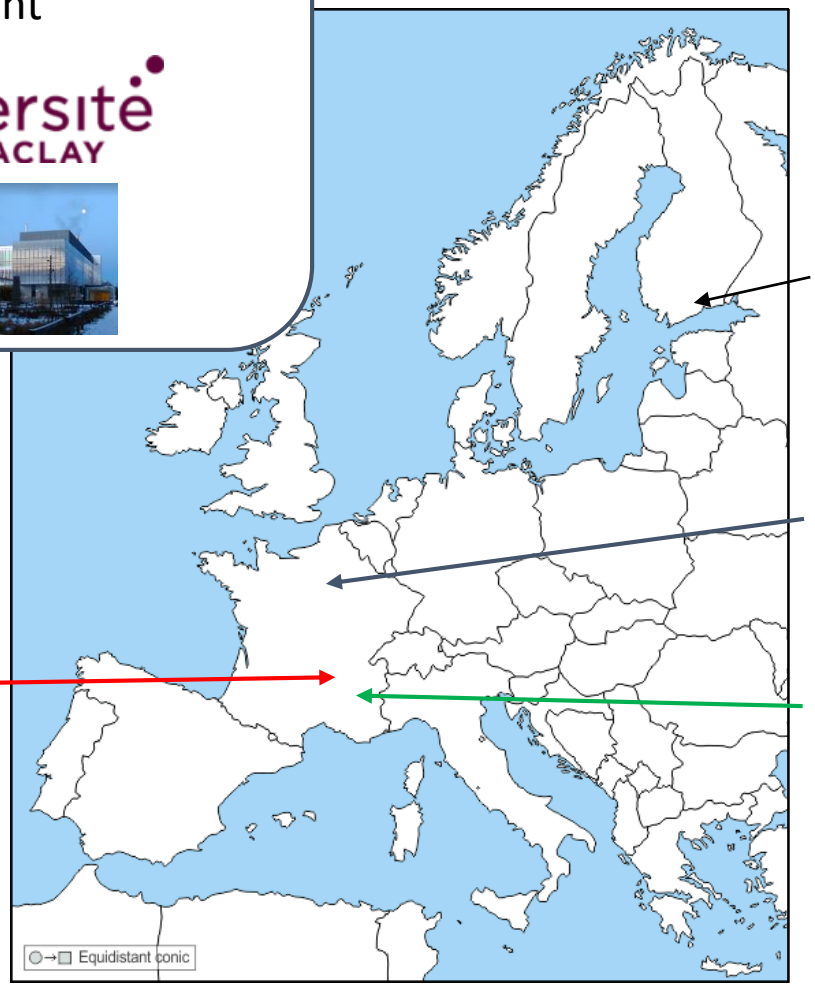
Research : C2N

Nanoscience and Nanotechnology center
Nanoelectronics department

C2N

université PARIS-SACLAY

cnrs



2003-2004 : post-doc
Helsinki U (Finland)

2000-2003 : PhD thesis
Sorbonne U

2000 : M2 (DEA) Physique
Matière et rayonnement
U Grenoble Alpes

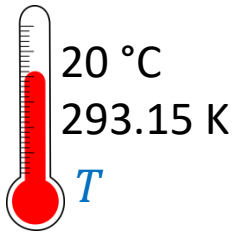
1996 - 2000 :
Magistere Physics
ENS Lyon

Quand l’électronique devient quantique !

Quantum electronics

Quantum electronics

- Today

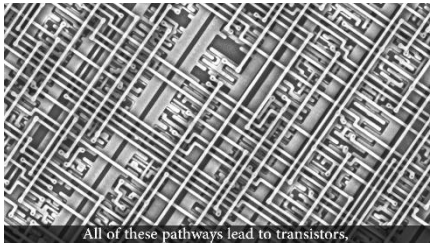


Flash memory

Tunnel effect

- Tomorrow

Complex and small systems
Intel transistor 4 nm announced for 2023 !

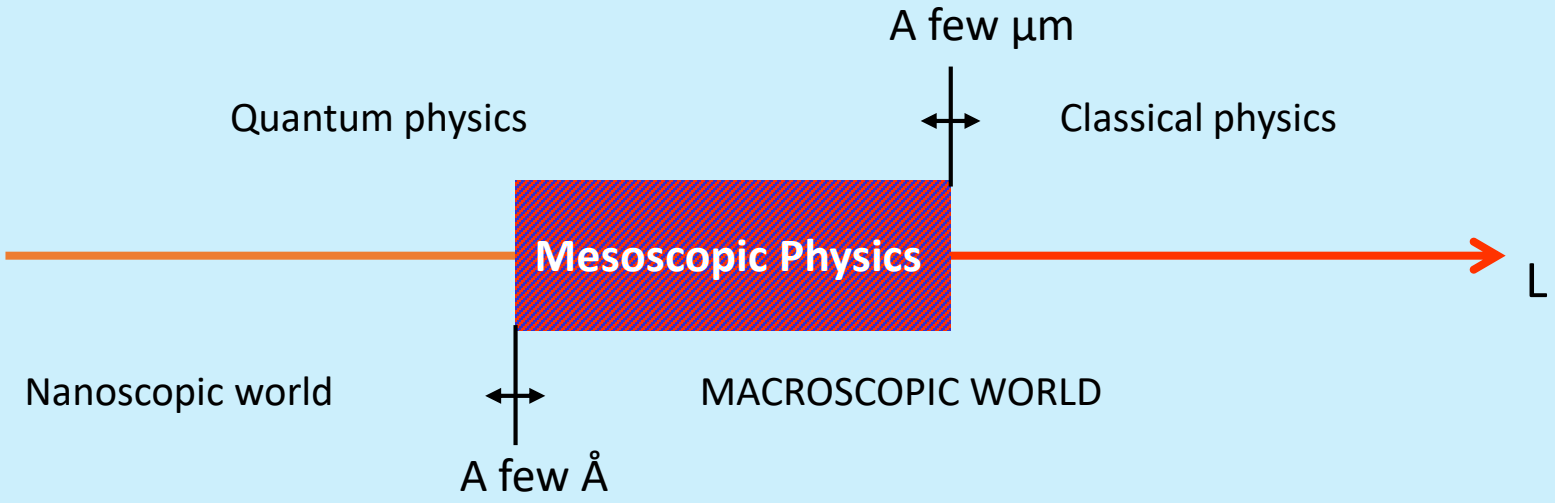


Quantum effects ?

- One day :

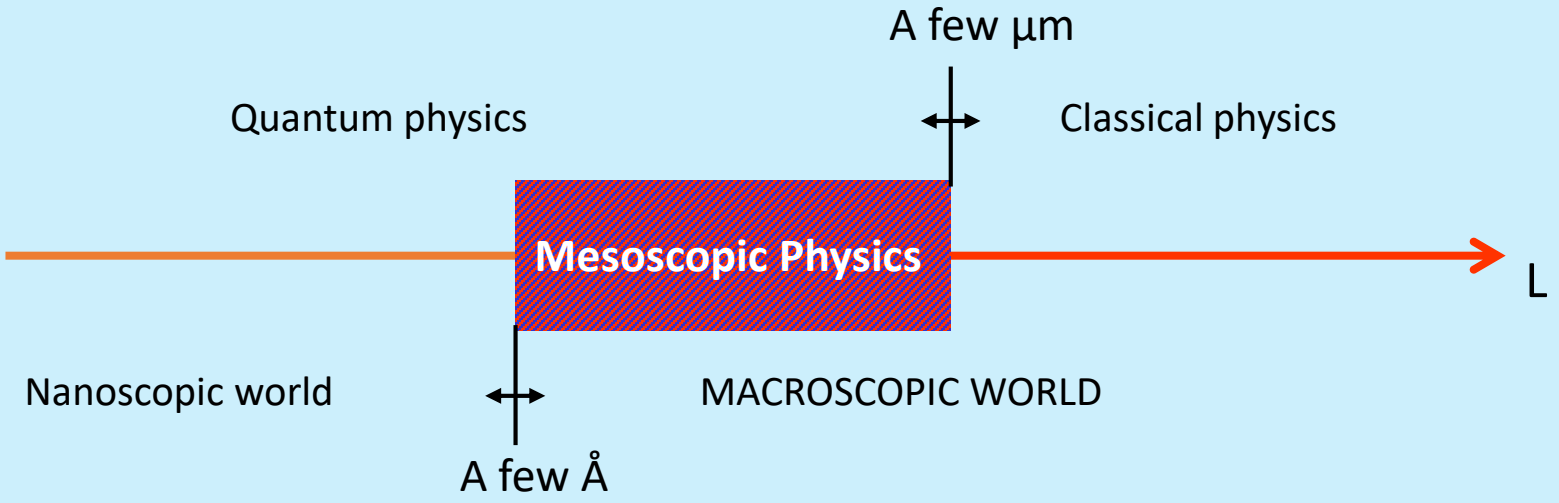
Quantum computer ?

Quantum phenomena in electronic nanocircuits



Future electronic devices ? Quantum coherence limits ?
Quantum transport rules ?

Quantum phenomena in electronic nanocircuits



Future electronic devices ? Quantum coherence limits ?
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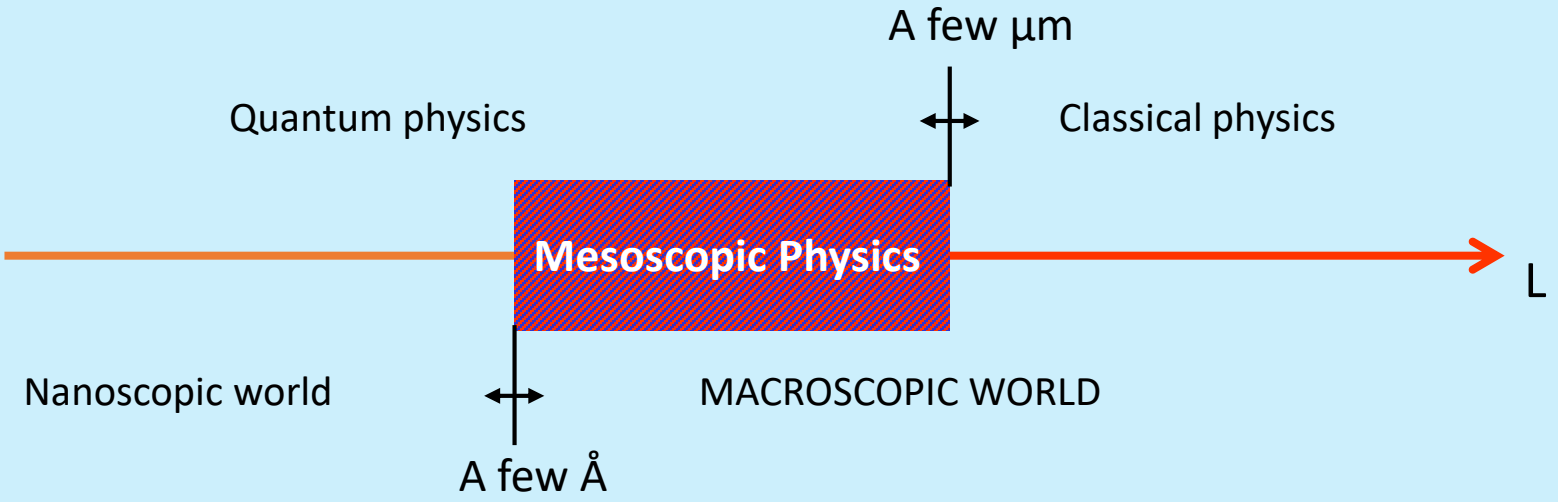
Circuit conception and clean room nanofabrication

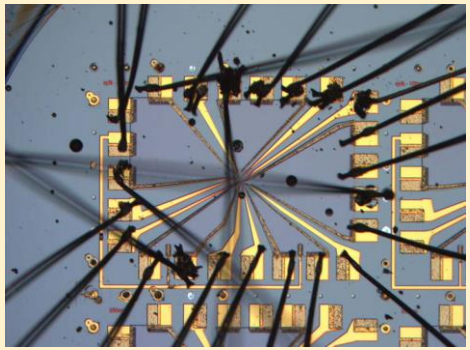
Quantum phenomena in electronic nanocircuits

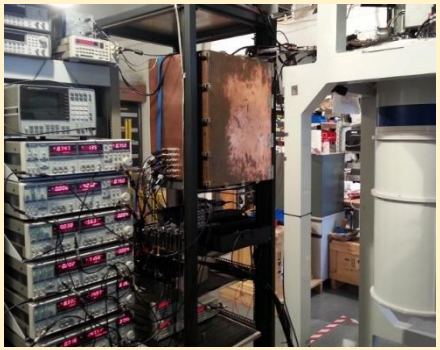


Future electronic devices ? Quantum coherence limits ?
Quantum transport rules ?

Circuit conception and clean room nanofabrication

Low temperature, low noise electronic measurements

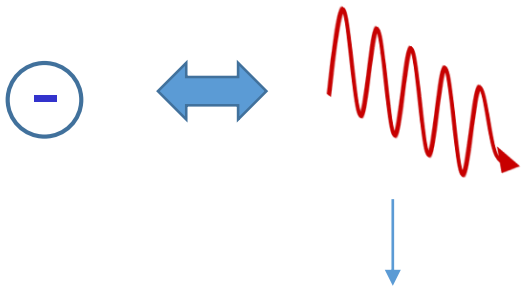




An example of experiment to test and improve electron quantum coherence in circuits

Electron

Particle – wave duality :



Coherence linked to wave description

How “electrons” can be coherent in a circuit ?

An electron in a piece of conductor

How “electrons” can be coherent in a circuit ?

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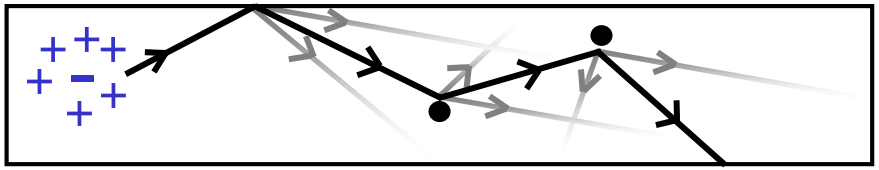

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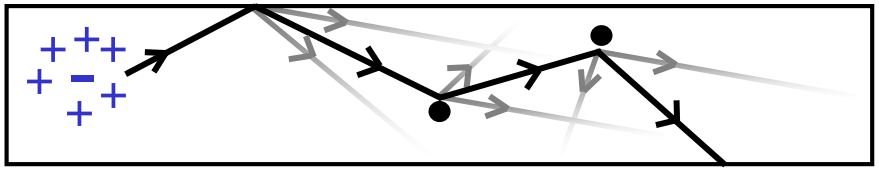

Elastic scattering

Diffusive states

$$\Psi_{el} = \psi_{el} e^{i\Phi_{el}}$$

Phase of electronic state

How “electrons” can be coherent in a circuit ?

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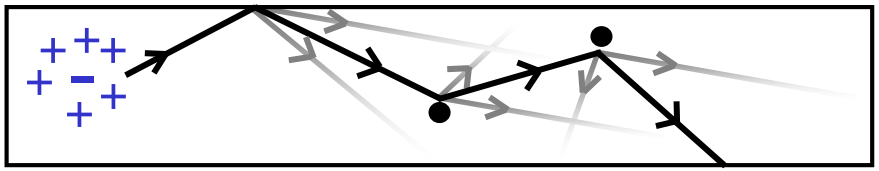

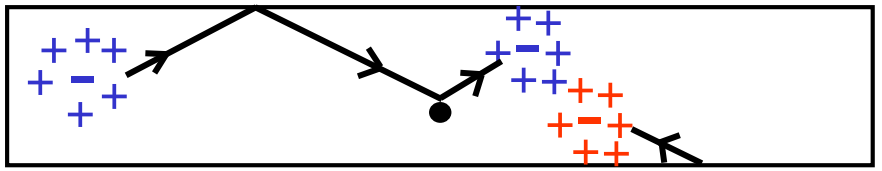

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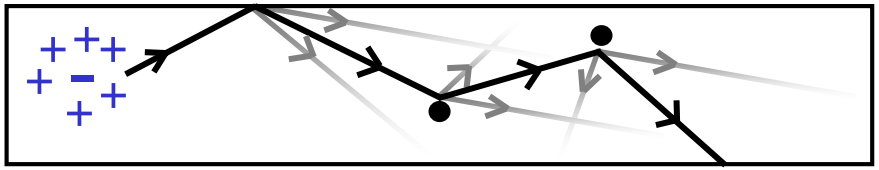

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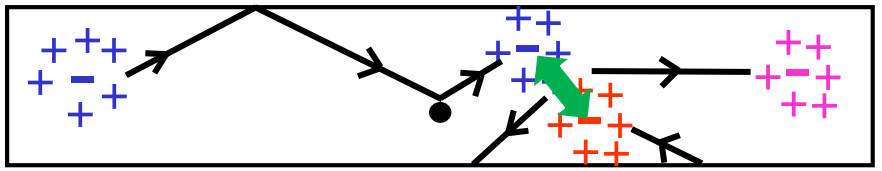
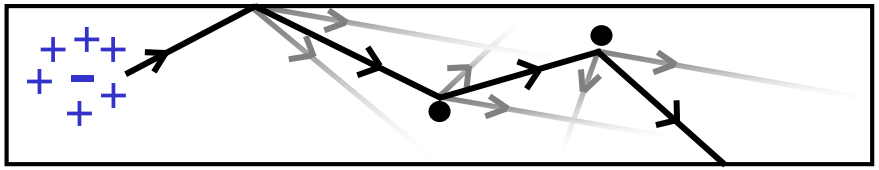


Inelastic scattering

Coulomb interaction
Energy exchange

How “electrons” can be coherent in a circuit ?

An electron in a piece of conductor



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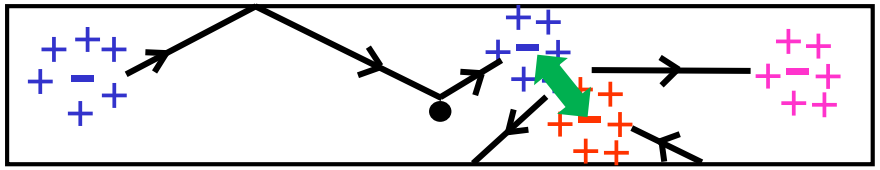

Inelastic scattering

Coulomb interaction
Energy exchange

Phase memory loss on a finite scale L_Φ

How “electrons” can be coherent in a circuit ?

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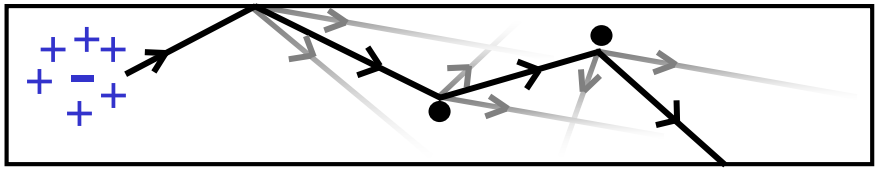

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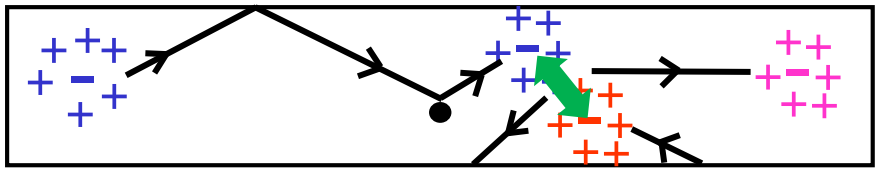


Inelastic scattering

Coulomb interaction
Energy exchange

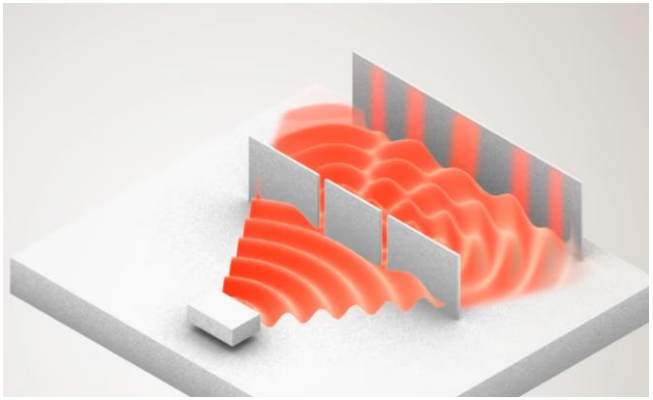
Phase memory loss on a finite scale L_Φ
~ 20 µm whatever materials at low temperature

How to test coherence ?

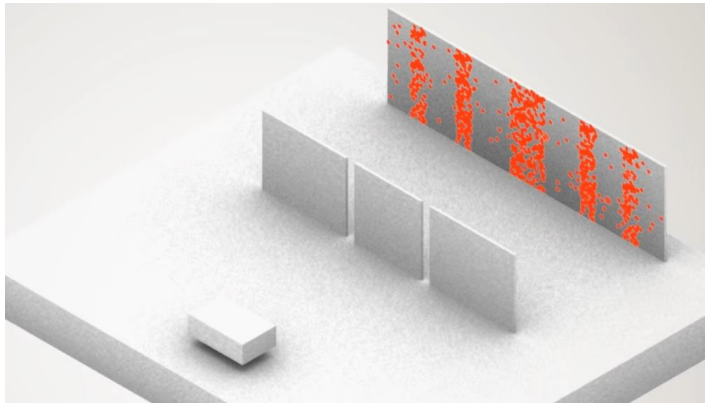
One way : interferometry

Wavefront splitting

Optics



Electronics



From https://toutestquantique.fr/
Chaire « La Physique Autrement » de la Fondation Paris Sud soutenue par le groupe Air Liquide

Not adapted for circuits

How to test coherence in circuits ?

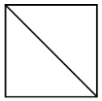
One way : interferometry

Amplitude splitting

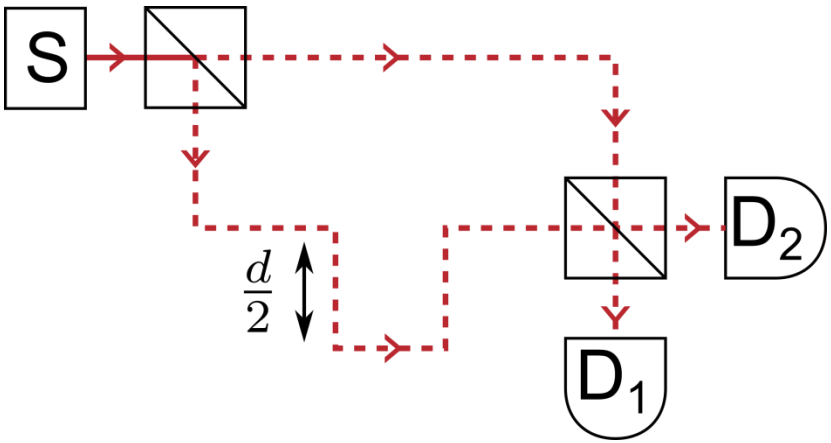
Optics

Light beams
Optical fibers

Beam splitters



☐ **Mach-Zehnder interferometer**



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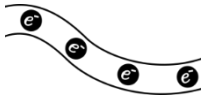
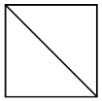
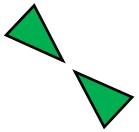


Electron beams
Quantum Hall channels

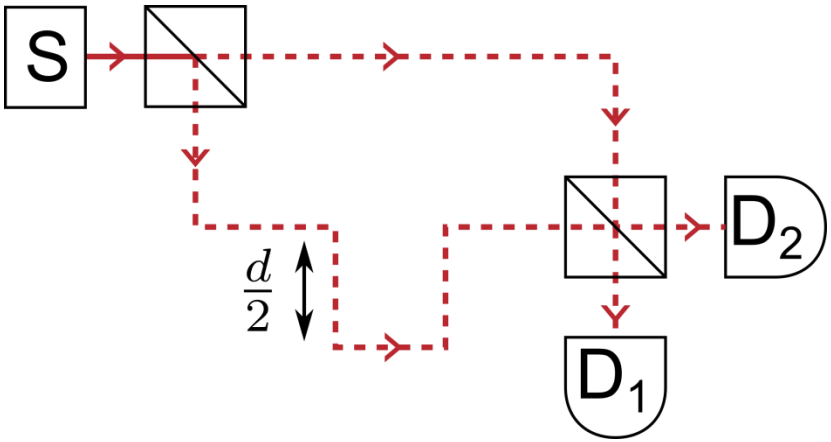
Beam splitters





Quantum point contacts

☐ **Mach-Zehnder interferometer**



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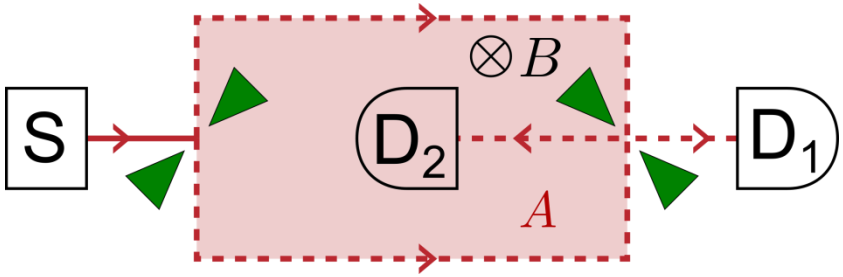
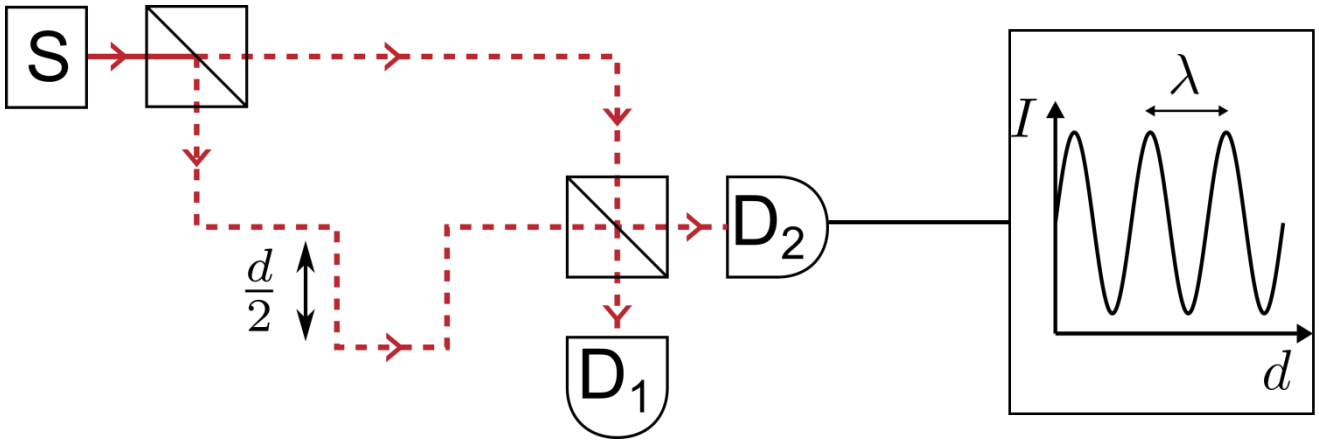


Fringes with a two-paths interferometer

Optical Mach-Zehnder interferometer



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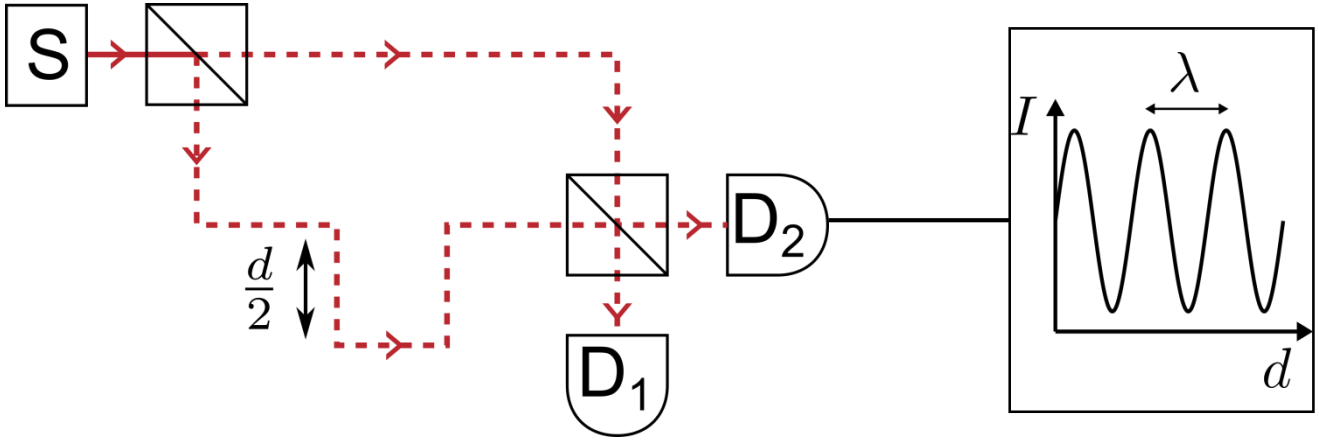
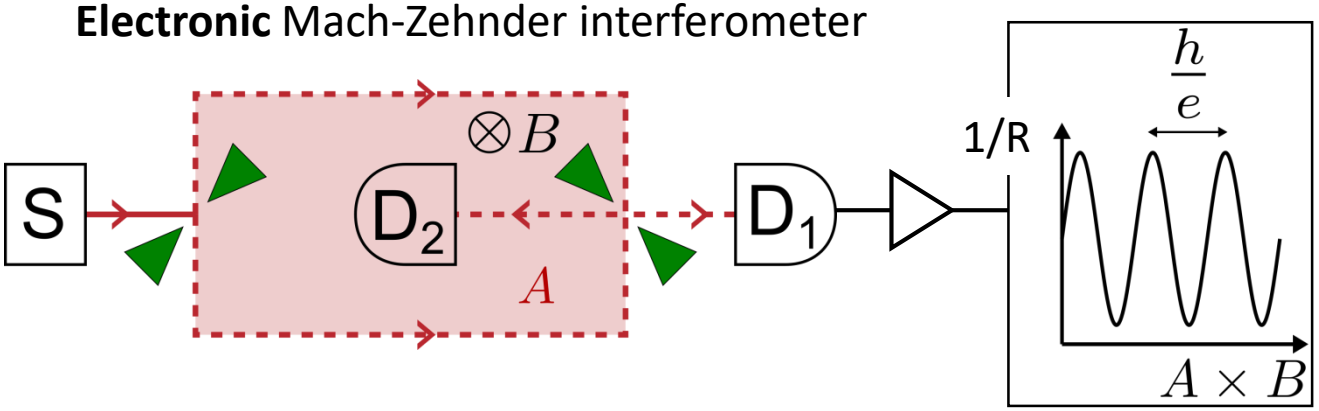
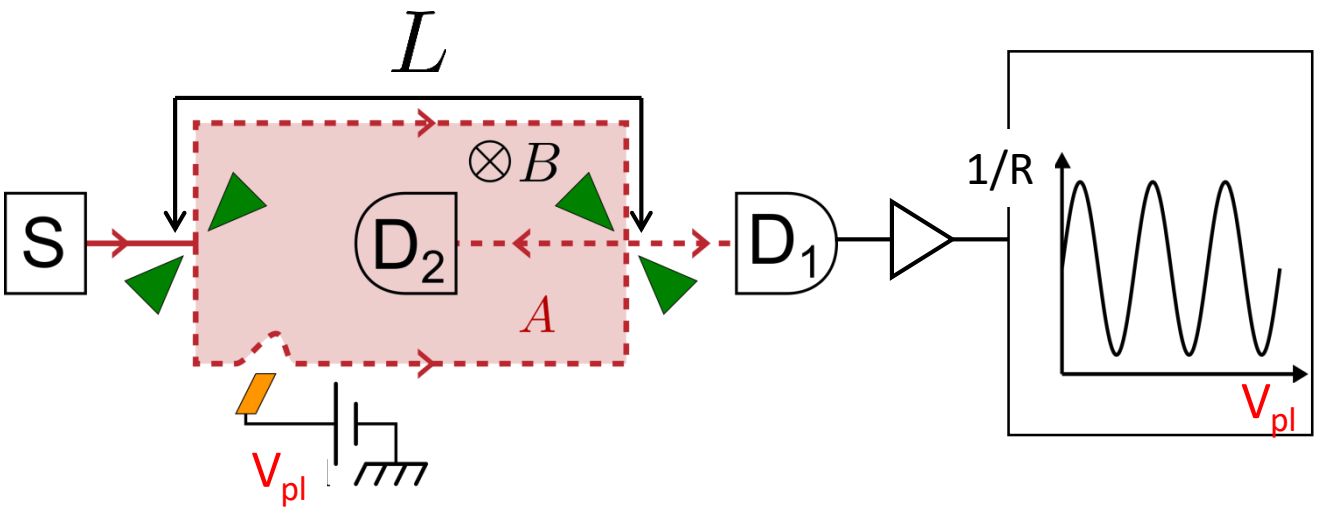


Electronic Mach-Zehnder interferometer

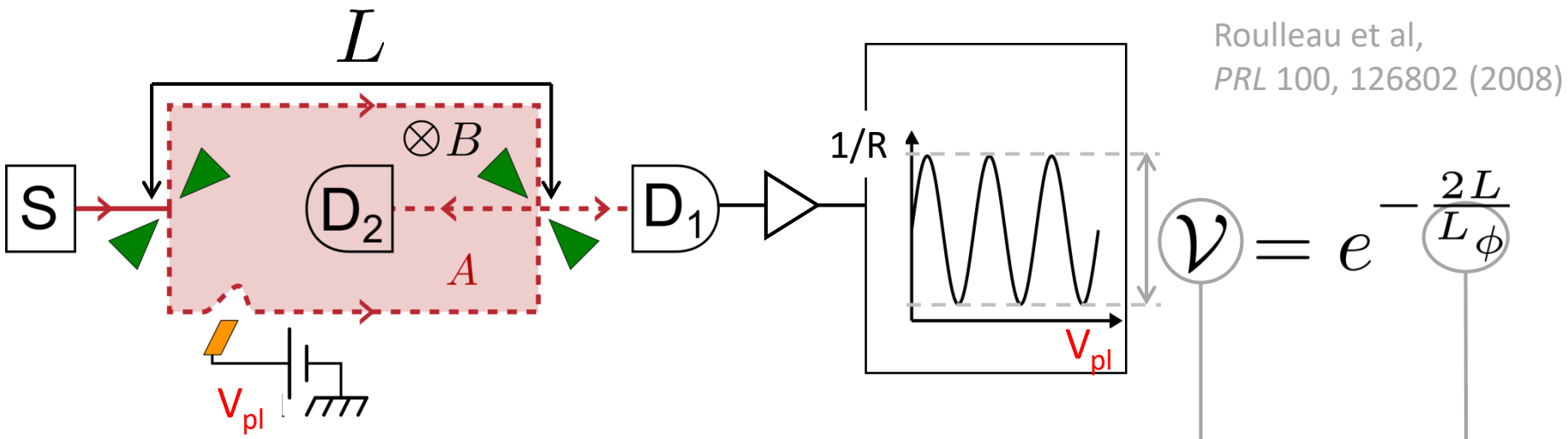


Probing coherence with a two-paths interferometer



Probing coherence with a two-paths interferometer

Electronic Mach-Zehnder interferometer



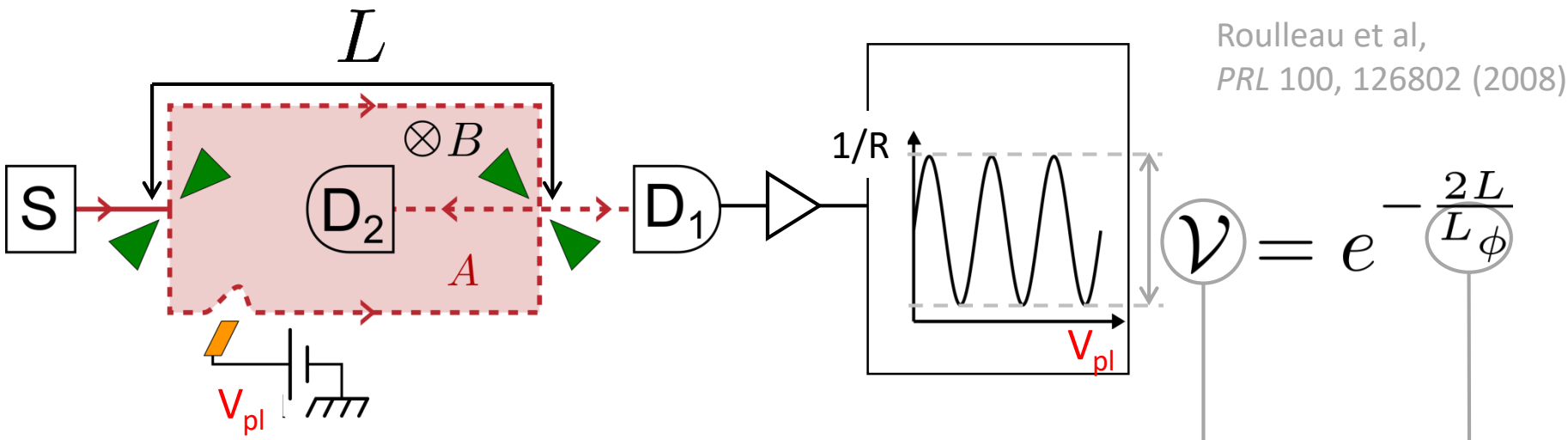
Roulleau et al,
PRL 100, 126802 (2008)

$$\mathcal{V} = e^{-\frac{2L}{L_\phi}}$$

Visibility

Coherence length

Probing coherence with a two-paths interferometer



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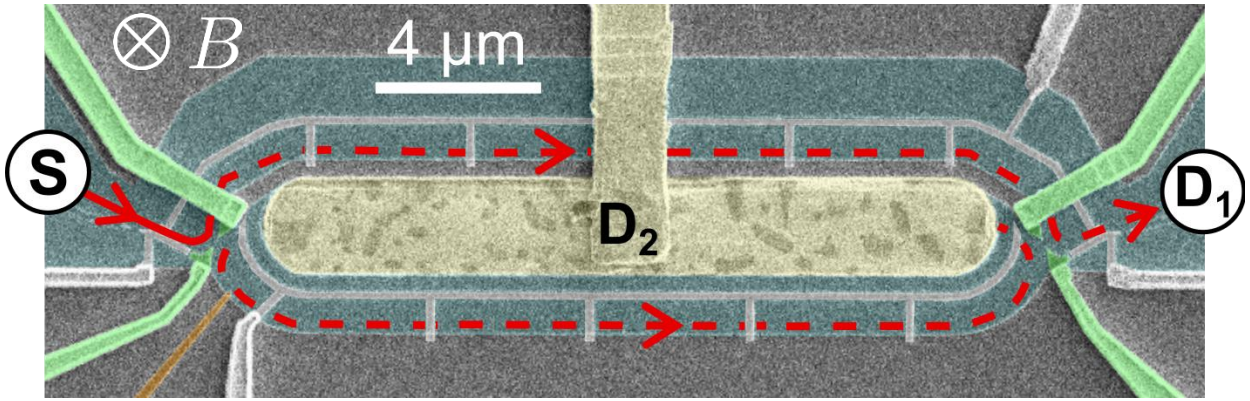
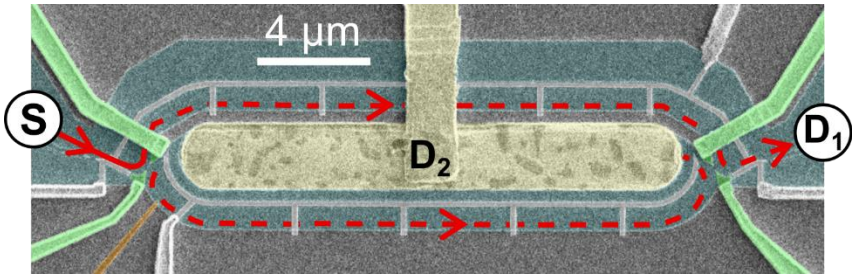


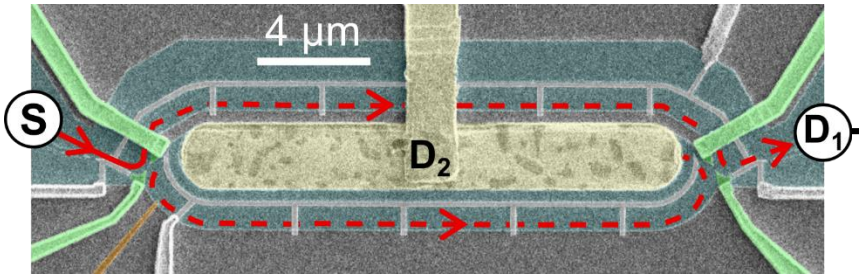
$L \approx 24$ µm

Coherence length ?



$T \approx 10\text{mK}$

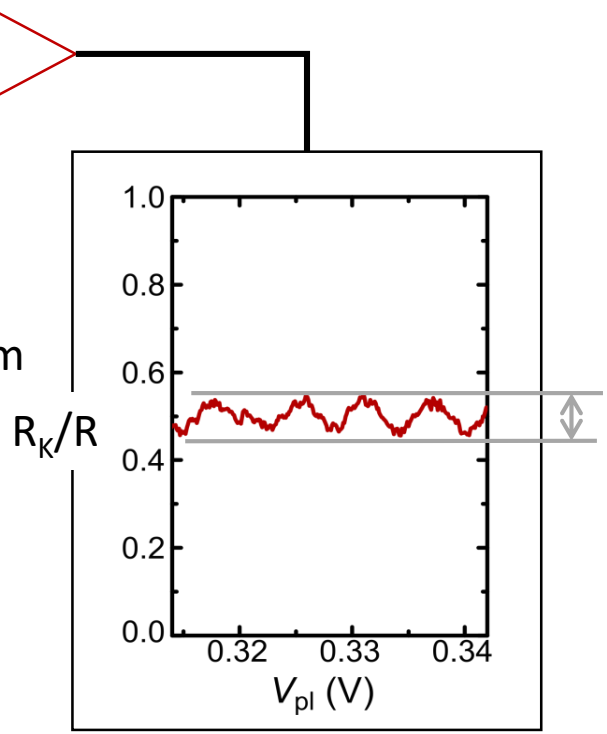
Coherence length ?



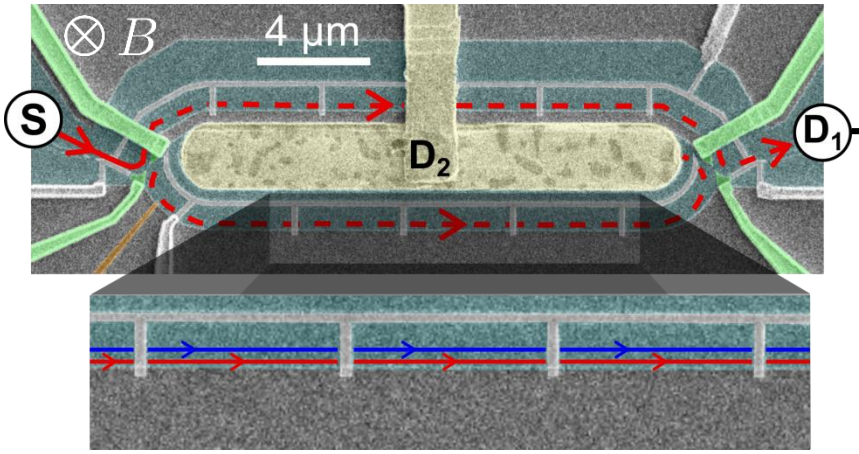
$T \approx 10\text{mK}$

$v \approx 6\%$

$L_\phi \approx 17\ \mu\text{m}$



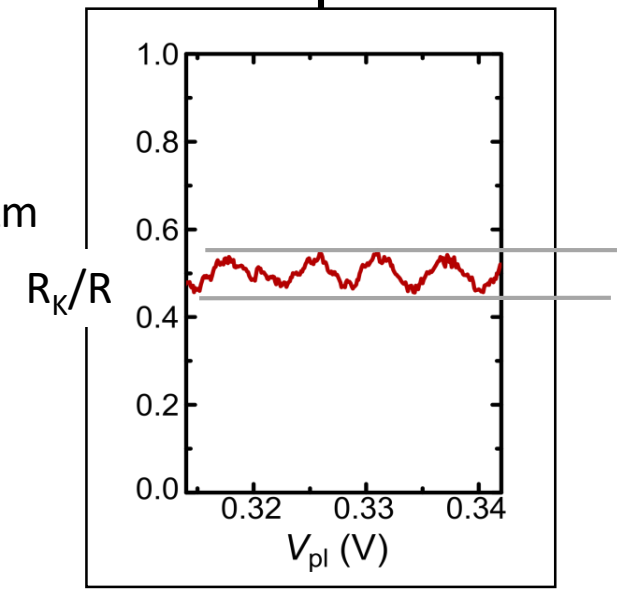
Coherence length ?



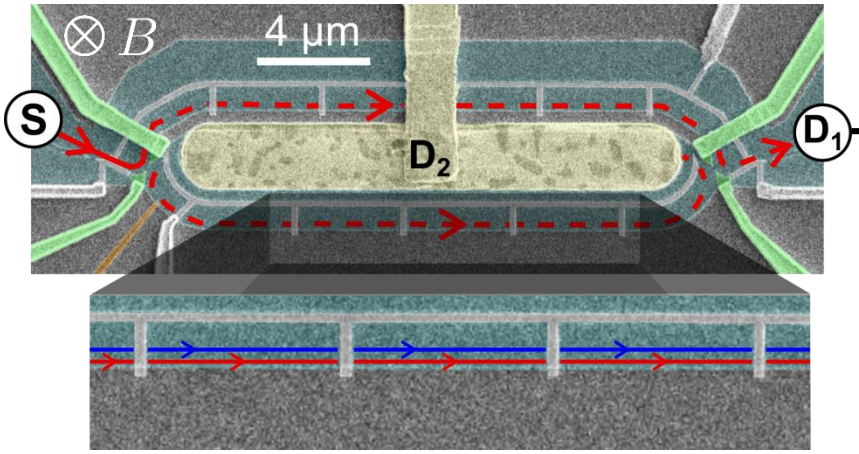
T = 10mK

$\nu \approx 6\%$

$L_\phi \approx 17$ µm



Increasing the coherence length with confinement ?



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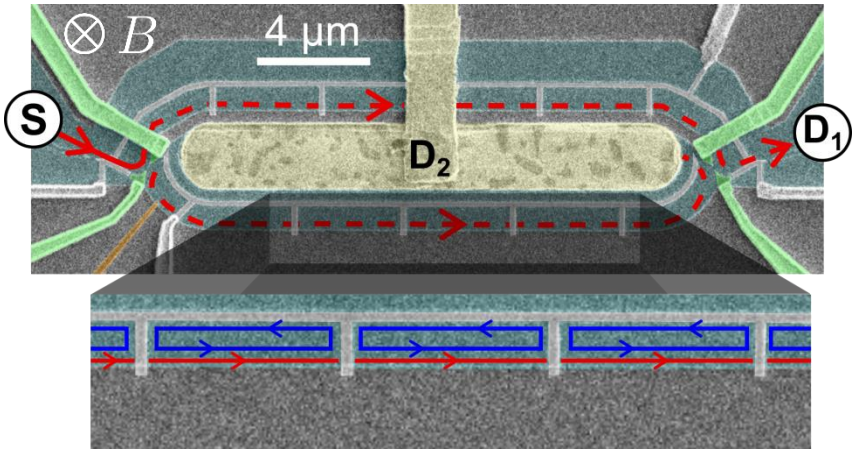
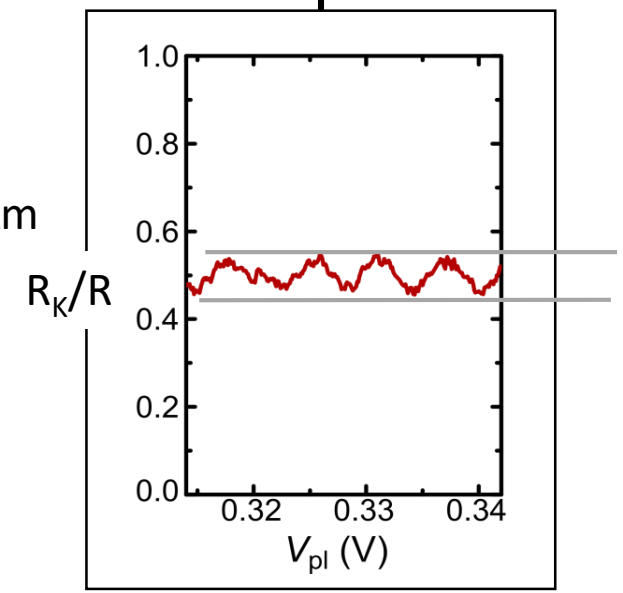


$\nu \approx 6\%$

$L_\phi \approx 17$ µm



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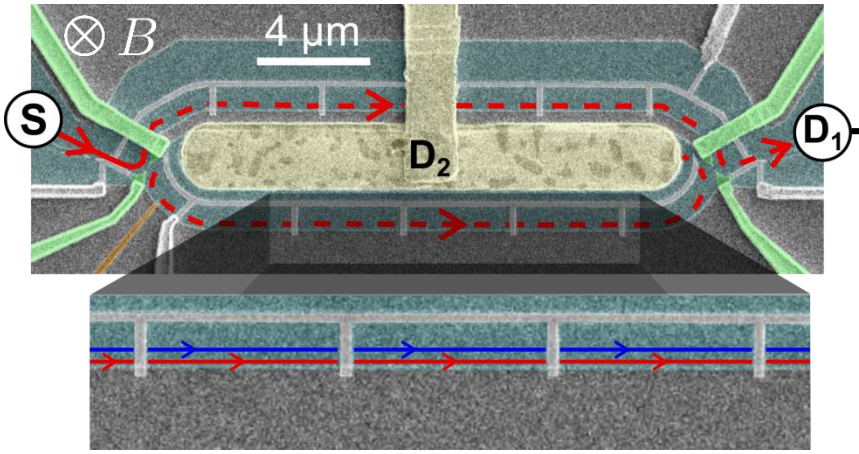
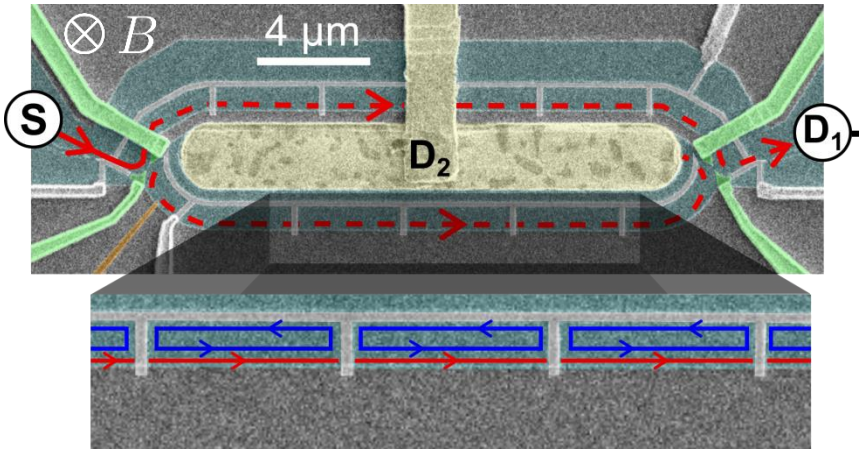


$T \approx 10$mK

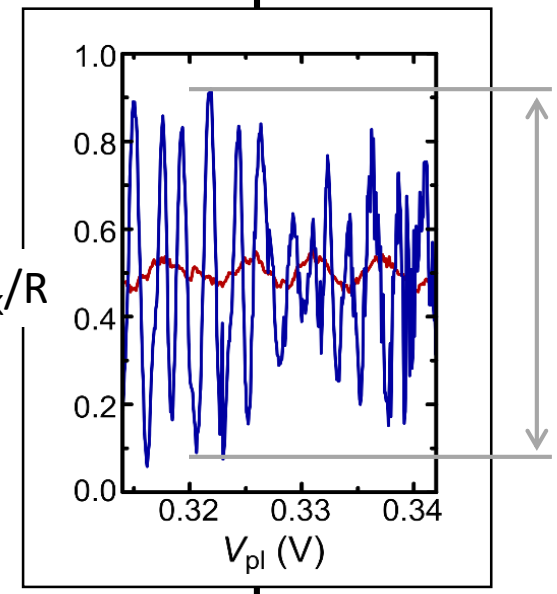


$\nu \approx 6\%$

$L_\phi \approx 17$ µm

$\nu \approx 82\%$

$L_\phi \approx 0.25$ mm



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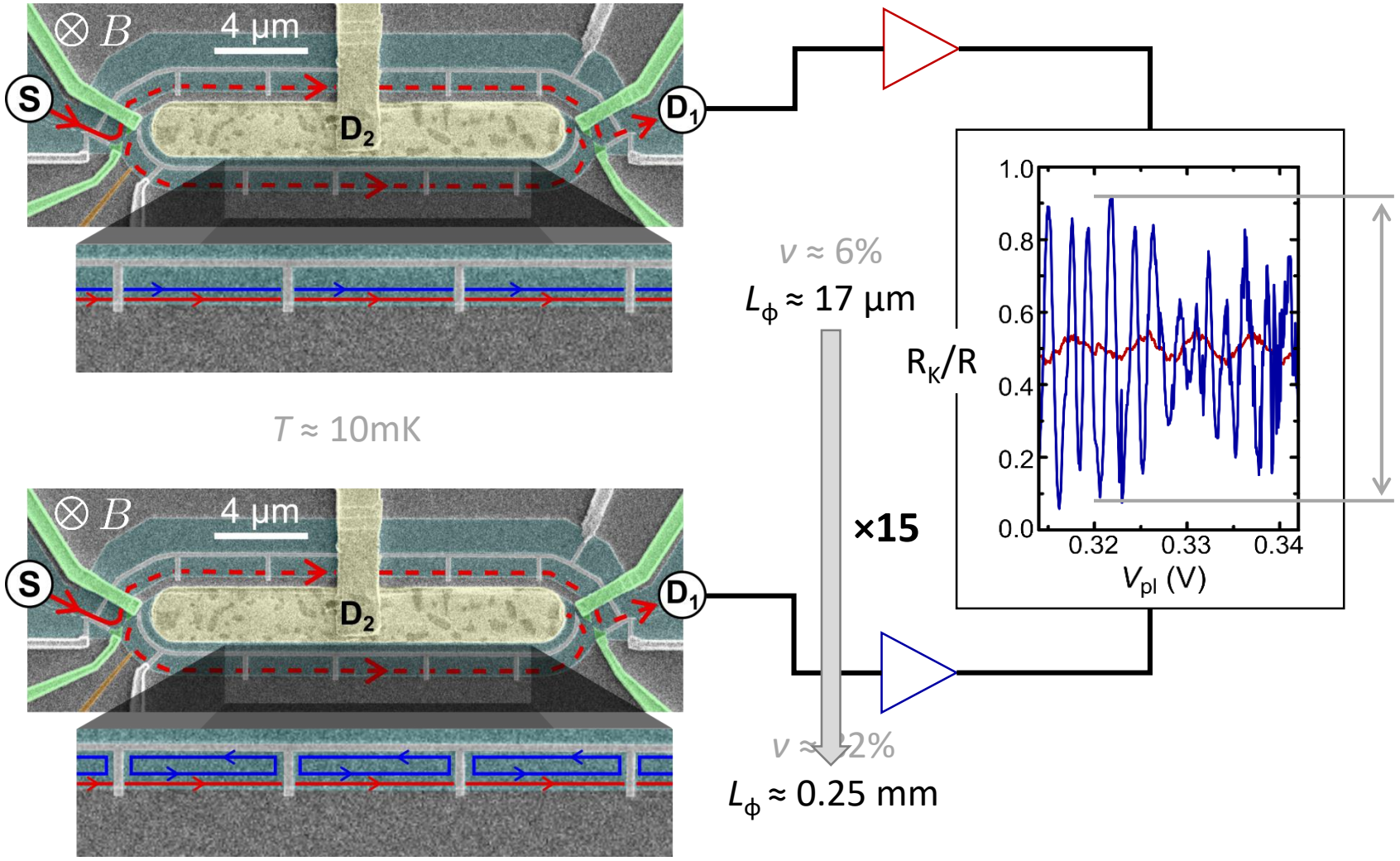

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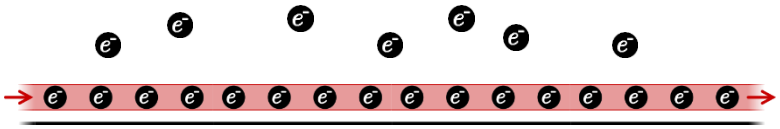
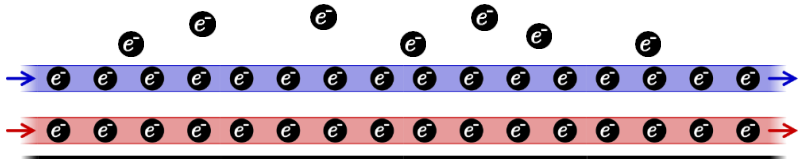
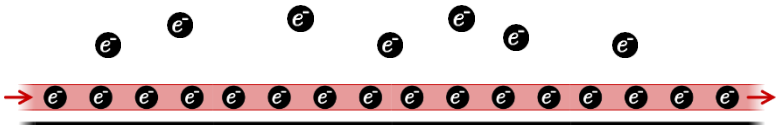


One beam : No measurable coherence length L_ϕ



One beam // Another beam $L_\phi \approx 17$ µm

Increasing the coherence length with confinement



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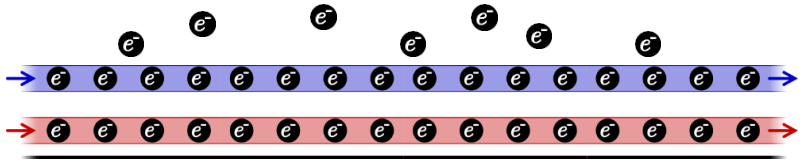
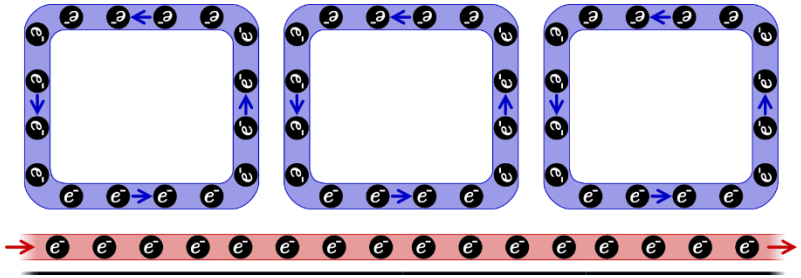


One beam // Another beam

$L_\phi \approx 17$ µm

×15

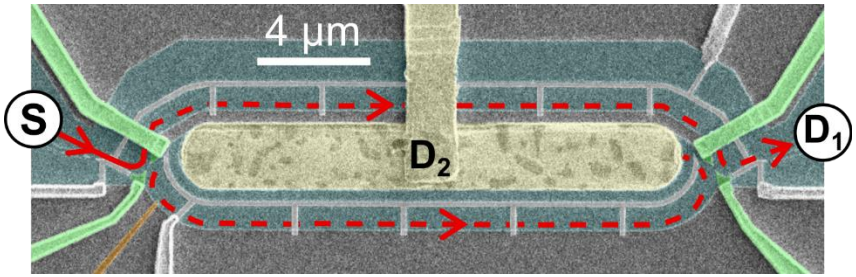


One beam // Another beam
with quantized levels

Fewer energy exchanges

$L_\phi \approx 0.25$ mm

Conclusion



$T \approx 10\text{mK}$

H. Duprez, E. Sivre, A. Anthore, A. Aassime, A. Cavanna, A. Ouerghi, U. Gennser, and F. Pierre, Macroscopic Electron Quantum Coherence in a Solid-State Circuit, Physical Review X **9**, 2 (2019)

A better understanding of Coulomb interaction effects

A record for measured electronic coherence length whatever materials and temperature

→ Towards electron quantum optics

Who worked on this experiment ?

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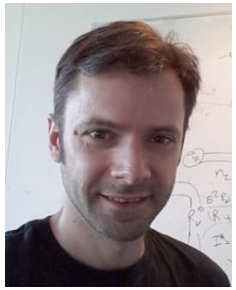

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