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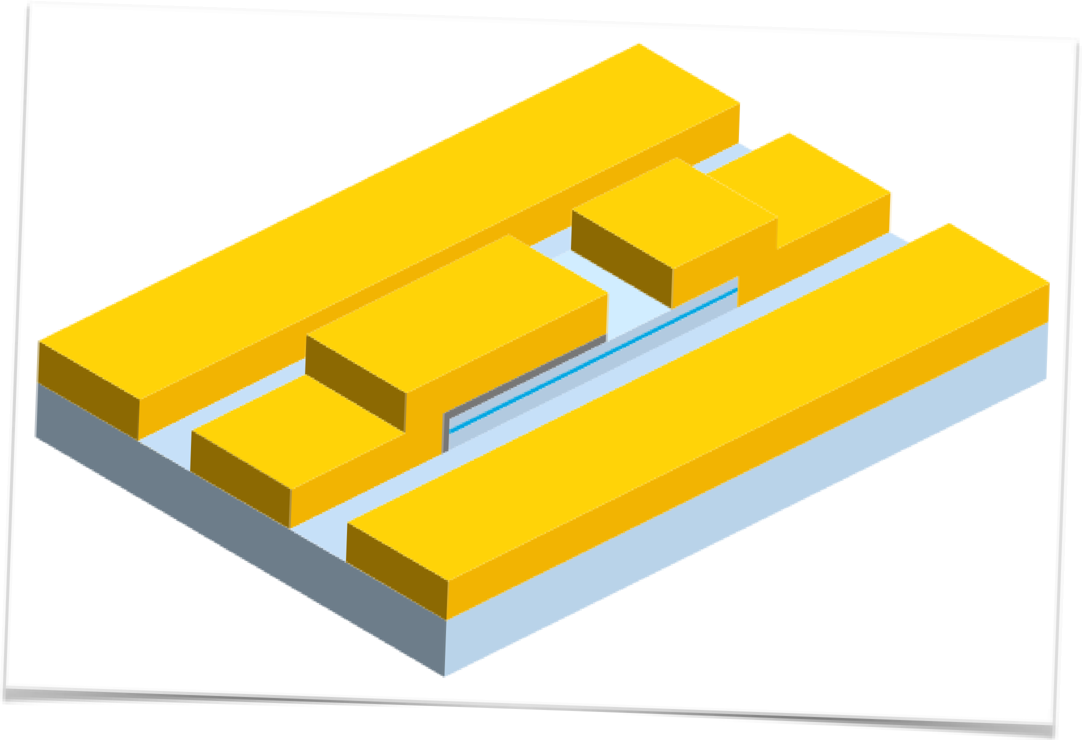
Dressed topological edge states in HgTe-based 2D topological insulators



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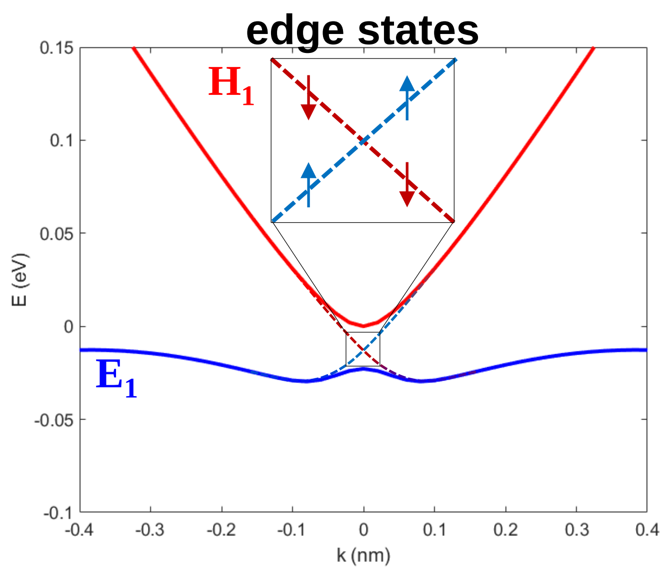
Discussion: D. Bercioux, T. Van Der Berg, R. Calvo

QSH edge states

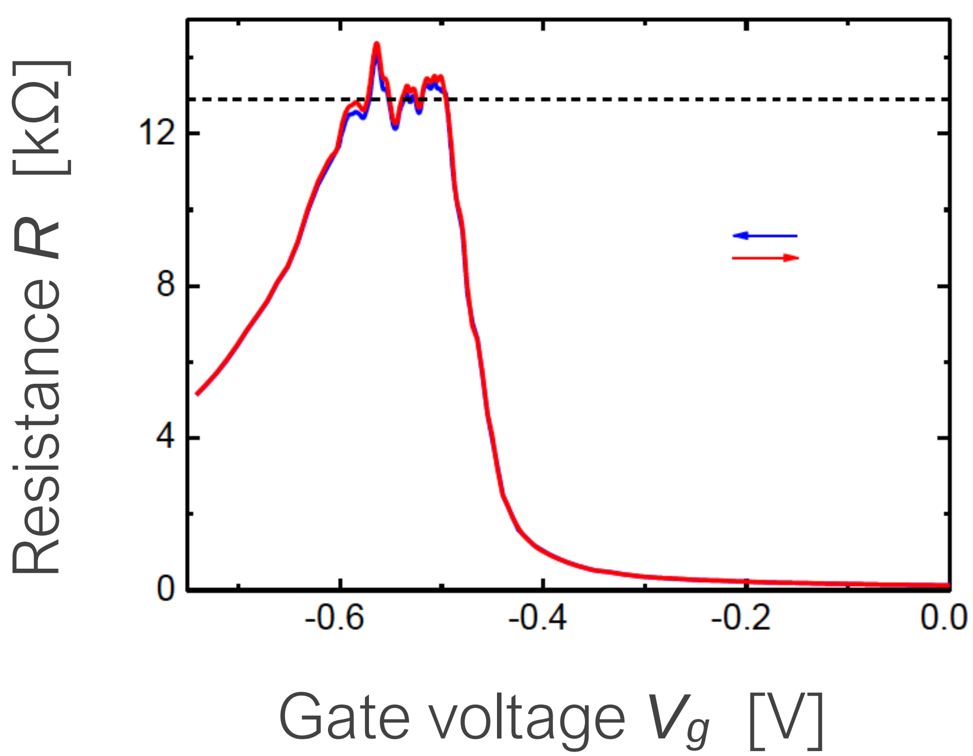
The HgTe quantum well:



- 2D topological insulator
- Helical edges states
- Spin polarised

Experimental observations:

M. König et al., Science, 318(5851):766, 2007
K. Bendias et al., Nanolett.4, 1839 (2018)



Many observations…

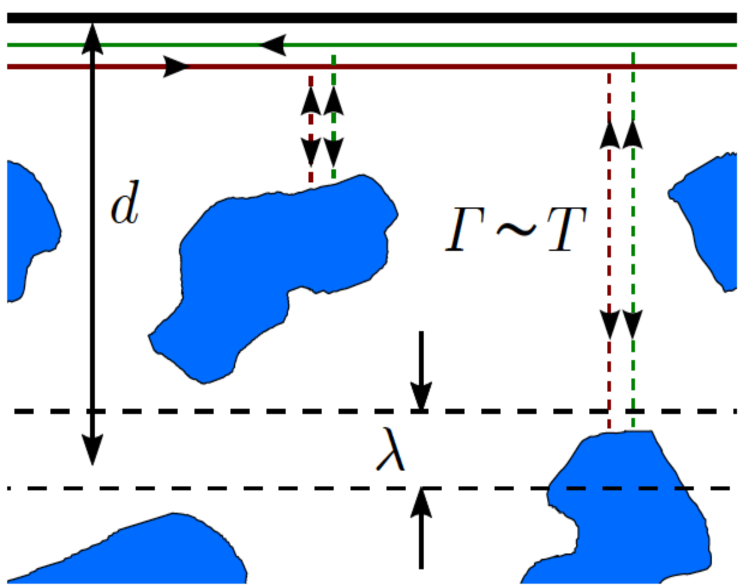
- *Quantized transport*
- *SQUID imaging*
- *…*

… but not robust:

*For **L>few µm** : R_{xx} is **not quantized anymore** $(h/(2e)^2)$*
→ Scattering appears

Microwave as a diagnostic tool

Many possible mechanisms: Charge puddles, e-e interactions, inhomogeneous SOC,…



J. I. Väyrynen *et al.*, PRL 110, 216402 (2013)

[1] A. Ström *et al.*, PRL 104, 256804 (2010)

[2] F. Crépin *et al.*, PRB 86, 121106 (2012)

[3] T. L. Schmidt *et al.*, PRL 108, 156402 (2012)

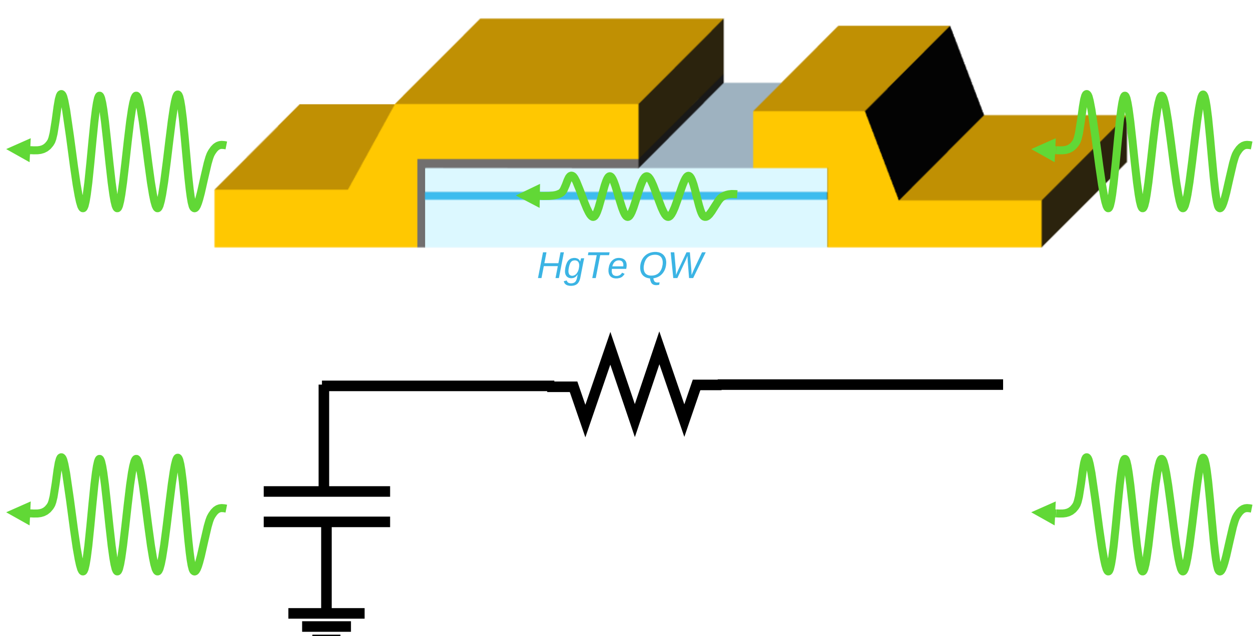
[4] S. Essert *et al.*, PRB 92, 205306 (2015)

[5] J. I. Väyrynen *et al.*, PRB 90, 115309 (2014)

[6] J. Maciejko *et al.*, PRL 102, 256803 (2009)

[7] F. Geissler *et al.*, PRB 89, 235136 (2014)

Probing from DC to microwaves:

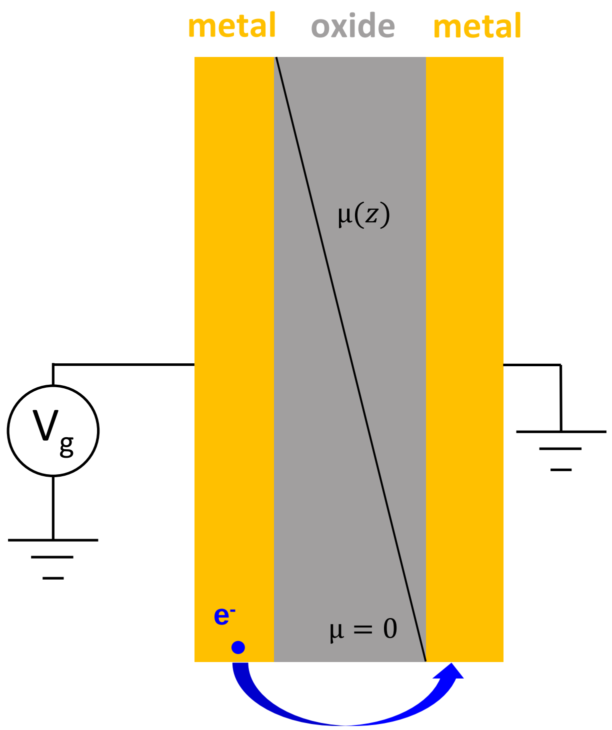


A powerful diagnosis tool :

- *Resistive response : **transport***
- *Capacitive coupling : **probe of DOS***
- ***Different dynamics for bulk and edges***

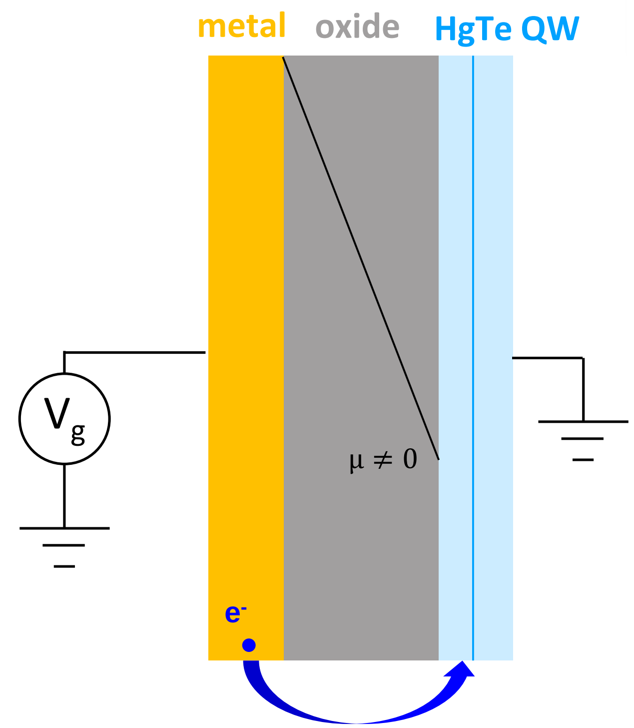
Probe DOS by quantum capacitance

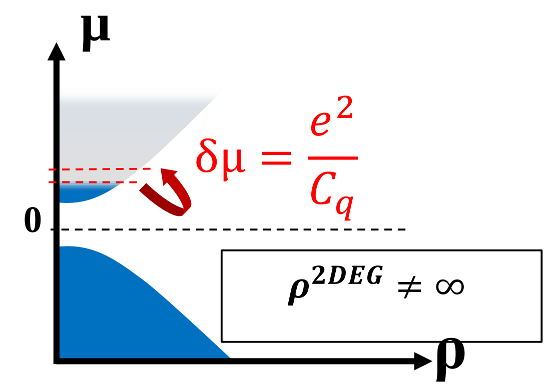
Metal-Oxide-Metal :

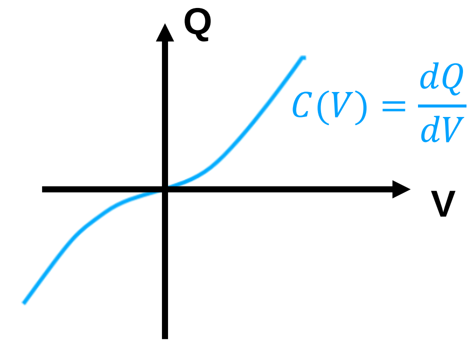


$$\Delta E = \frac{e^2}{C_{geo}}$$

Metal-Oxide-Topological Insulator :







$$\Delta E = \frac{e^2}{C_{geo}} + \frac{e^2}{C_q}$$

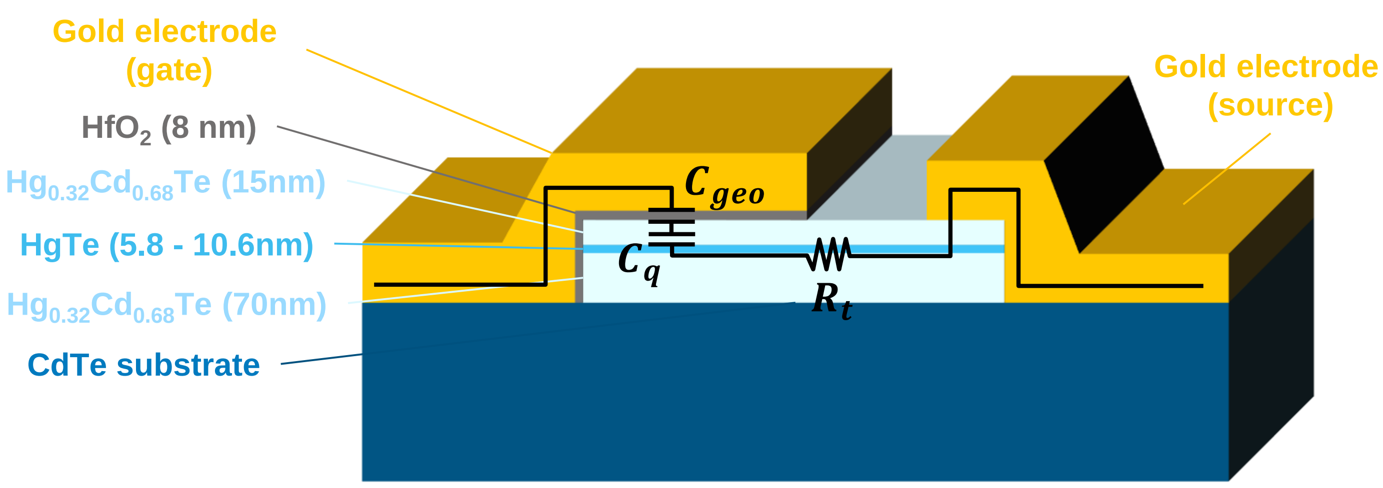
$$\boxed{C_q(\mu) = e^2 \frac{\partial n}{\partial \mu} = e^2 \rho(\mu)}$$

$$\mu(V_g) = \int_0^{V_g} \left(1 - \frac{C_t(V)}{C_{geo}}\right) dV$$

Probing C_q = probing the DOS

Experimental set-up

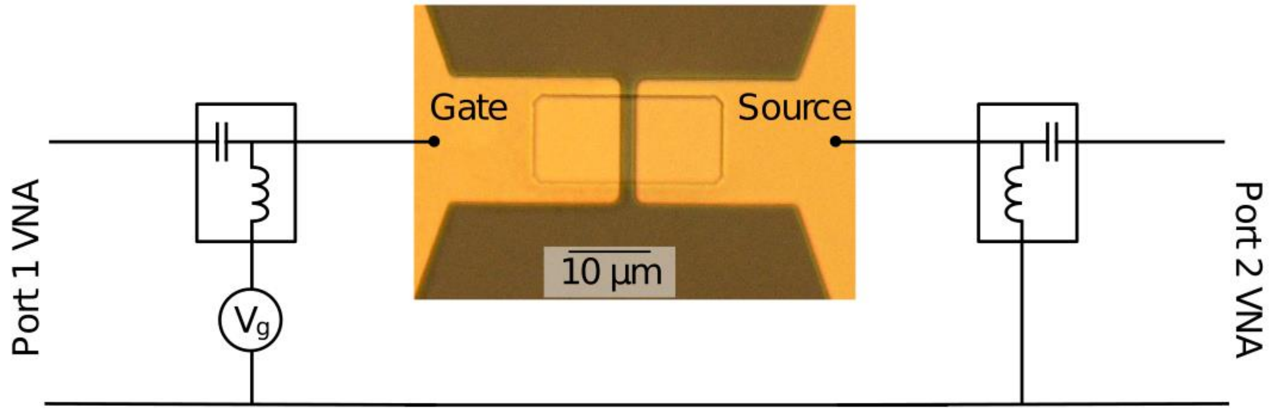
Sample:



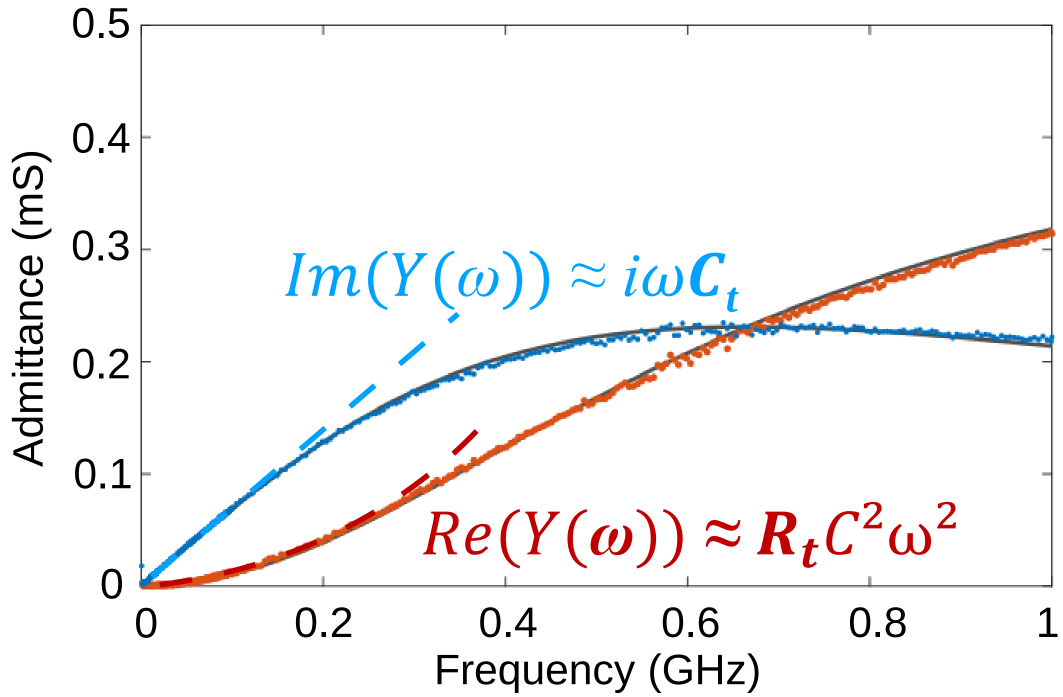
Cryogenic probe station:

$T \approx 10K$

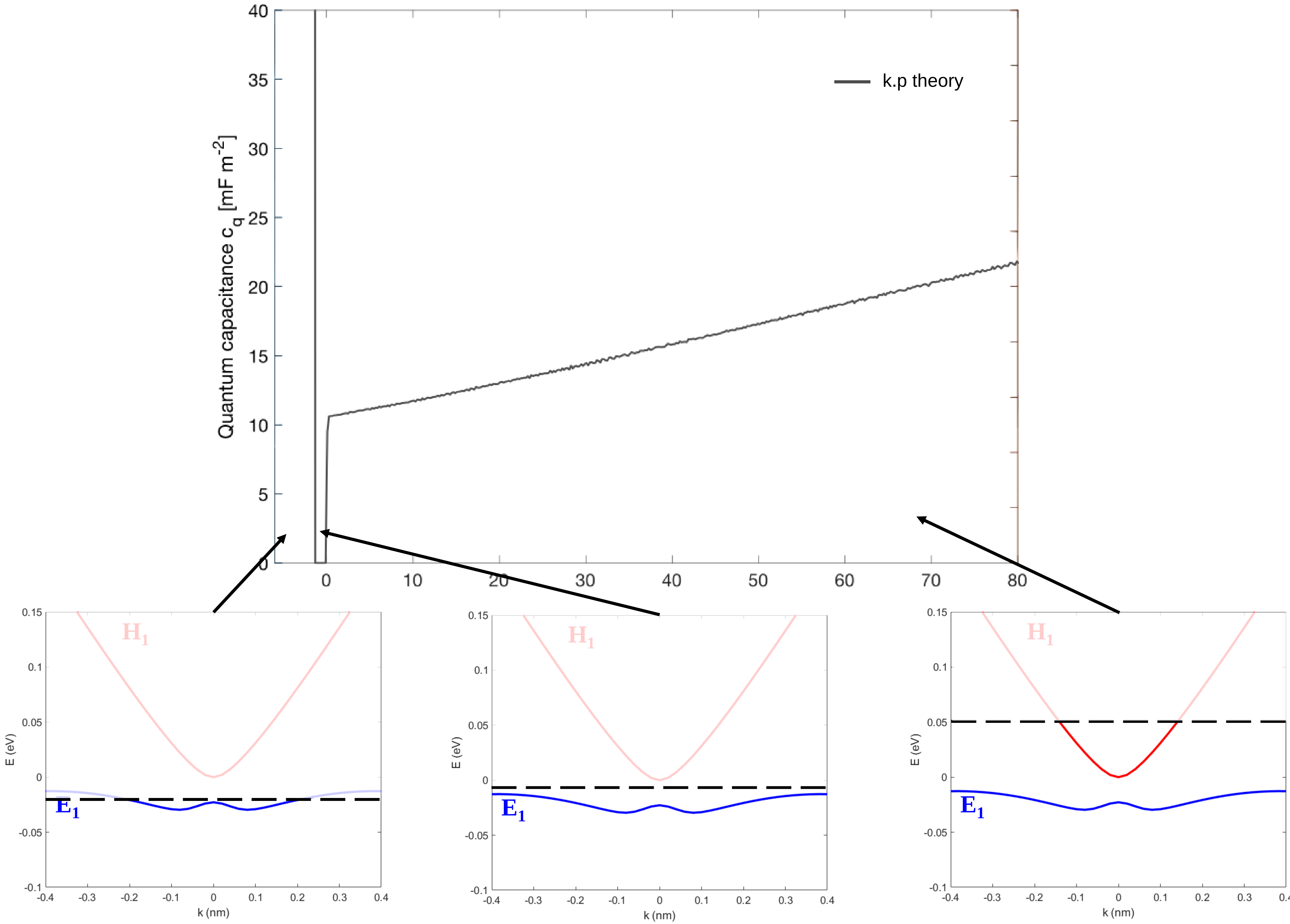
Vector Network Analyzer measurement:



R & C extraction (low frequency):

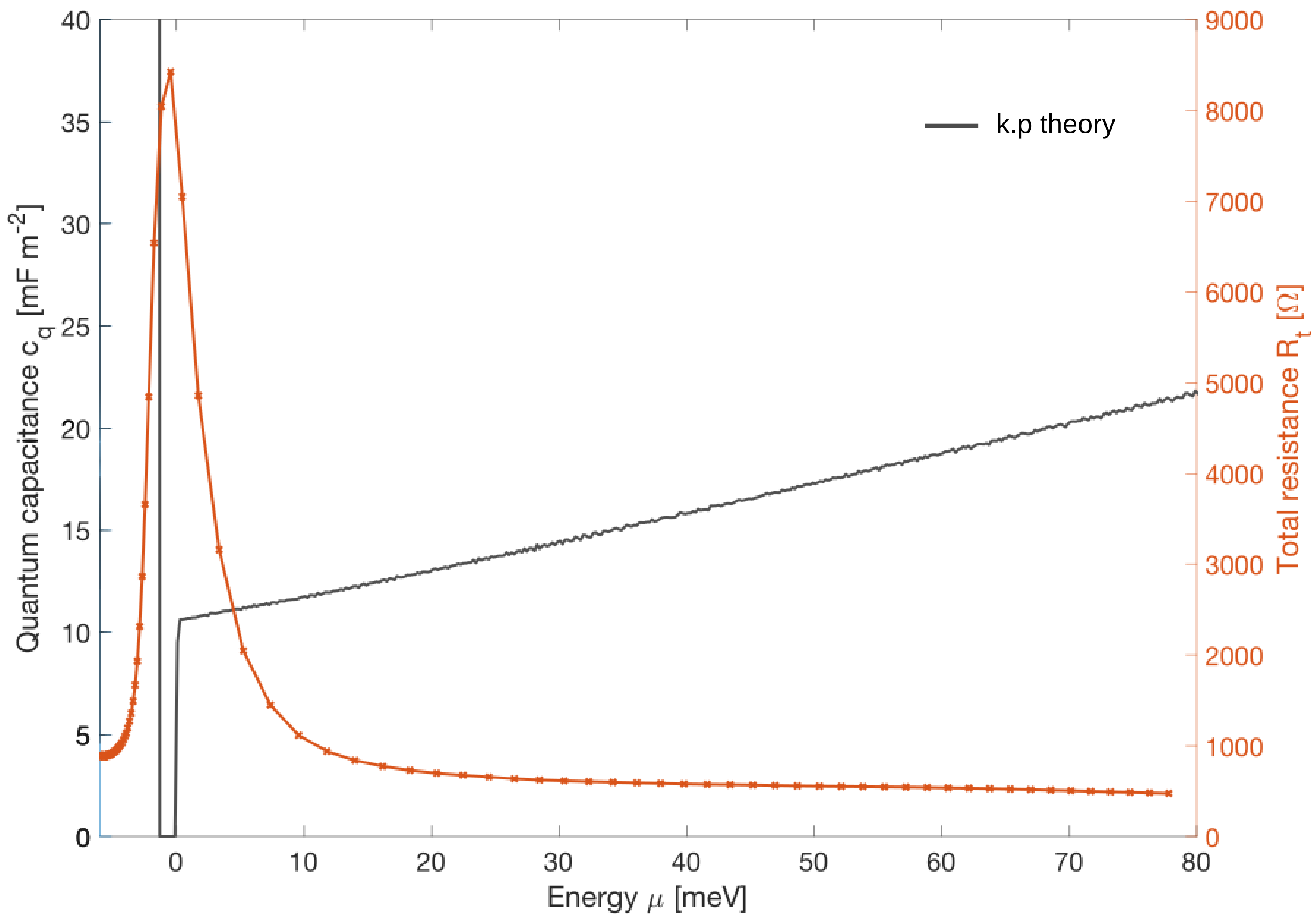


R_t & C_q vs μ



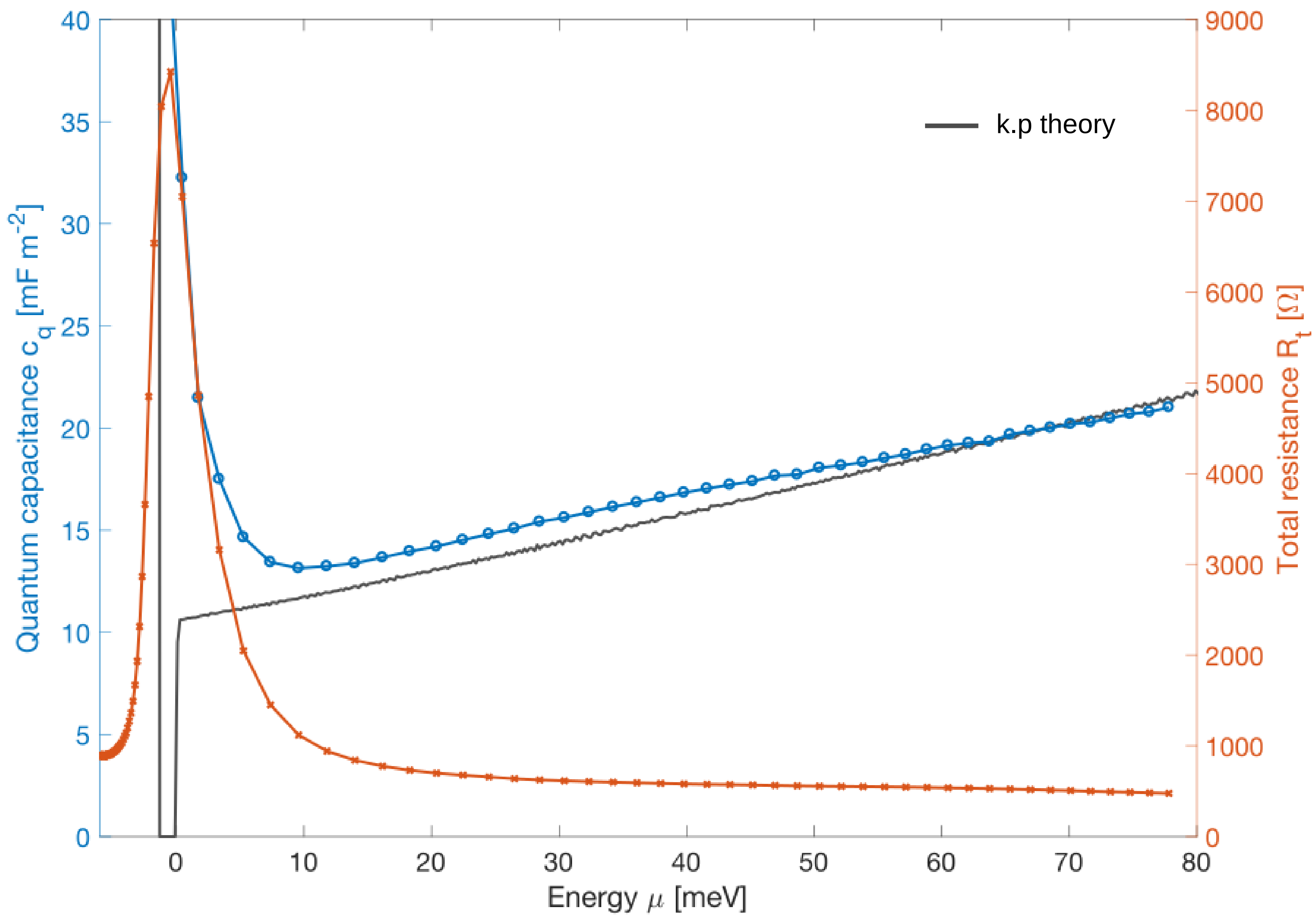
Quantum capacitance c_q [mF m^{-2}]
40
35
30
25
20
15
10
5
0
0
10
20
30
40
50
60
70
80
k.p theory
H_1
E_1
E (eV)
k (nm)
0.15
0.1
0.05
0
-0.05
-0.1
-0.4
-0.3
-0.2
-0.1
0
0.1
0.2
0.3
0.4

R_t & C_q vs μ



- R_t peak aligned with the gap

R_t & C_q vs μ

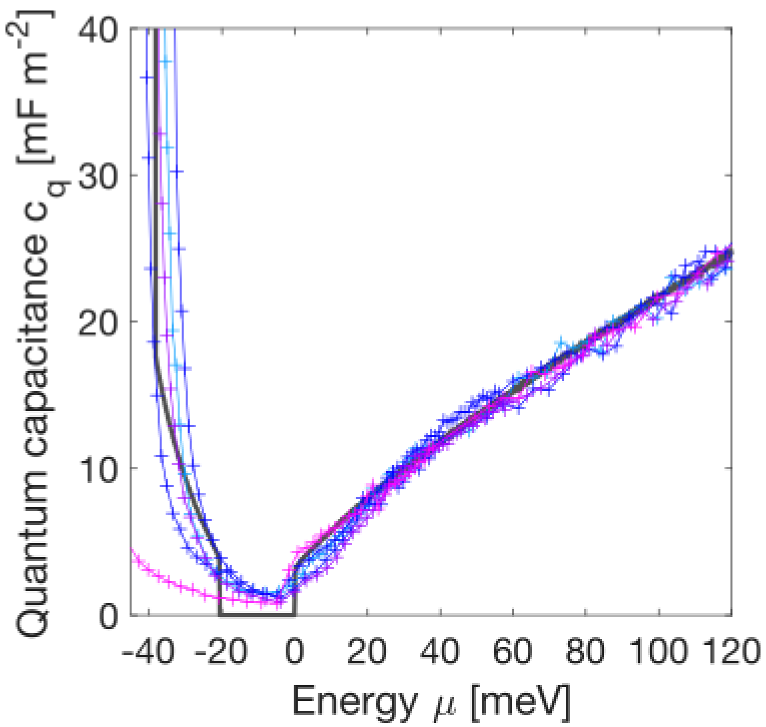


- R_t peak aligned with the gap
- C_q good averall agreement at high μ…
- … but smear in the gap → inhomogeneities/disorder

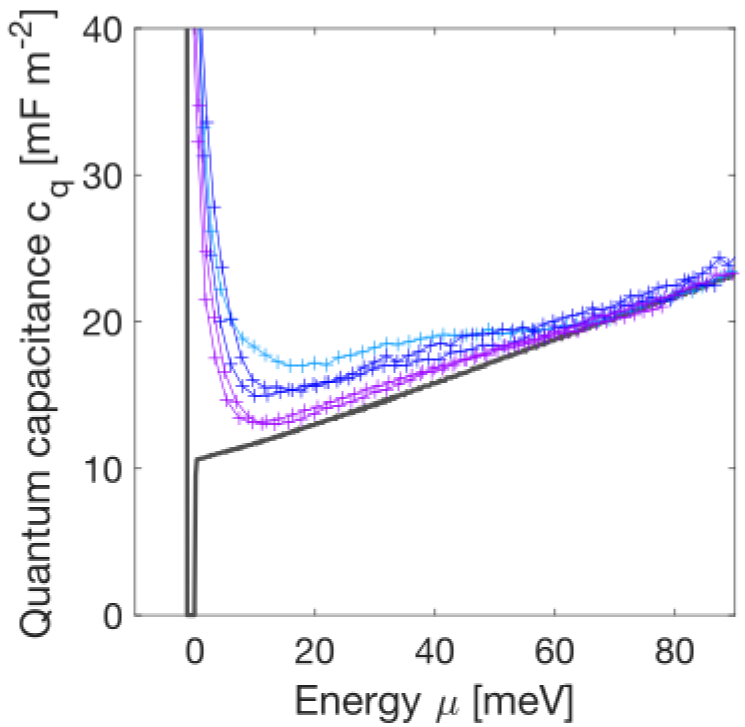
Can we distinguish our (1D) edges states ? → length study

Length dependence

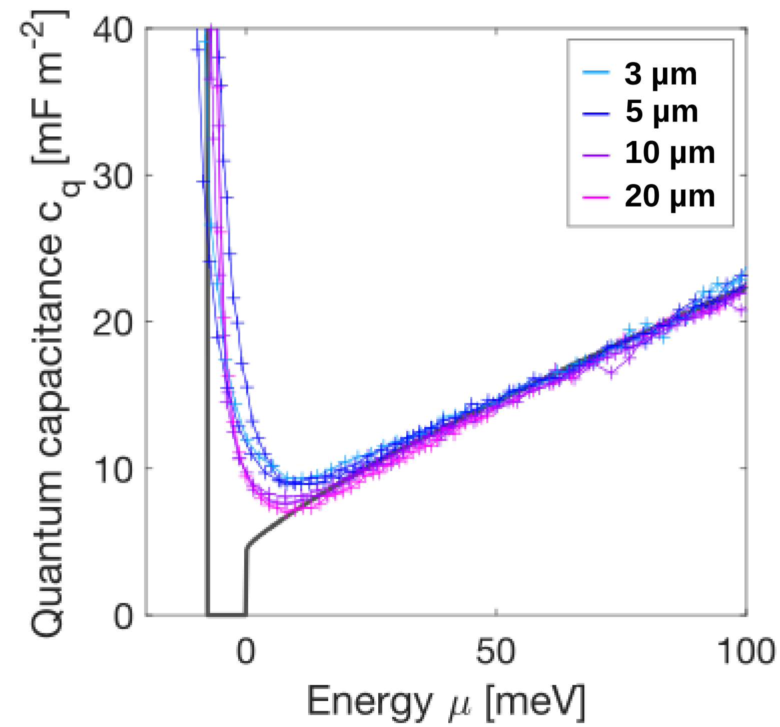
Trivial (5.8nm)

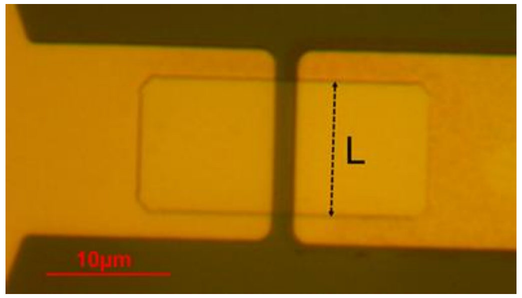


Topological A (10.6nm)



Topological B (8nm)



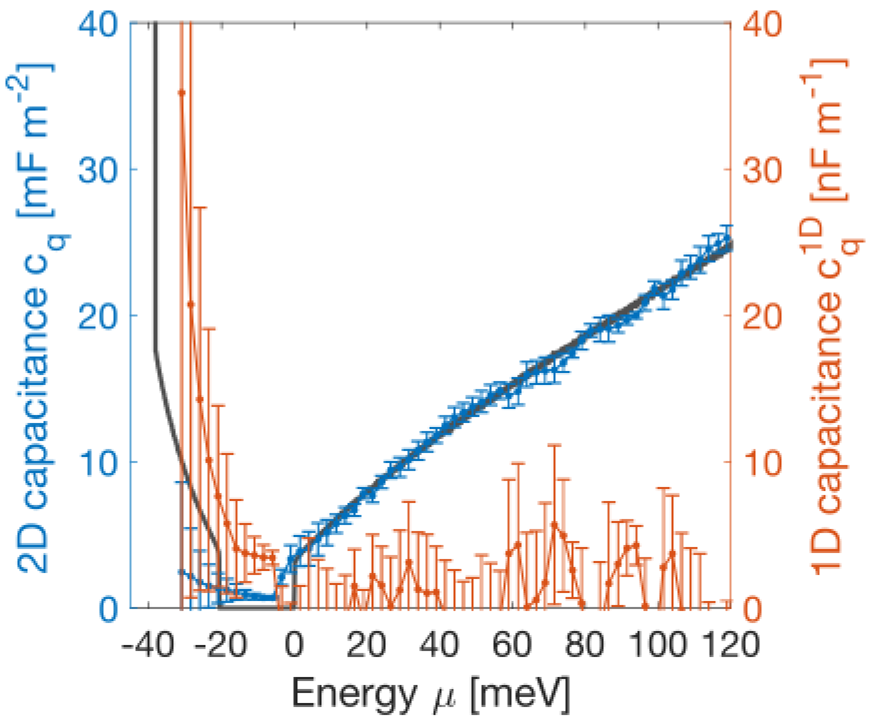


- L = 3, 5, 10, 20 µm
- No length dependance for trivial
- Clear length dependence for Topological A, B and other samples (not shown)

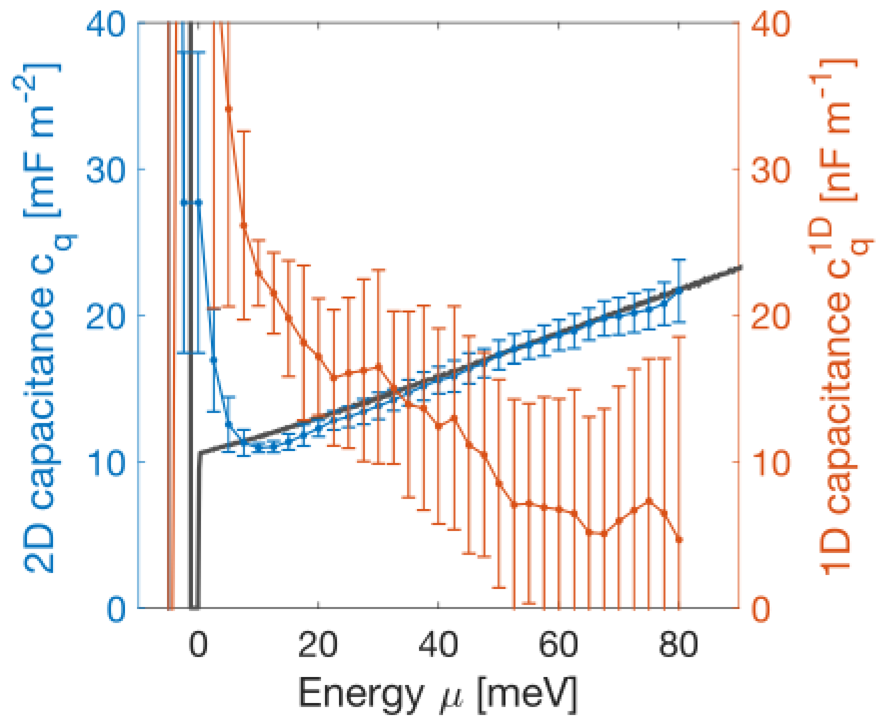
$$C_q = c_q^{2D} L^2 + 3c_q^{1D} L \xrightarrow[\textbf{by A = L}^2]{\textbf{Normalized}} \boxed{c_q = \underbrace{c_q^{2D}}_{\text{bulk}} + \underbrace{\frac{3c_q^{1D}}{L}}_{\text{edge}}}$$

Length dependence

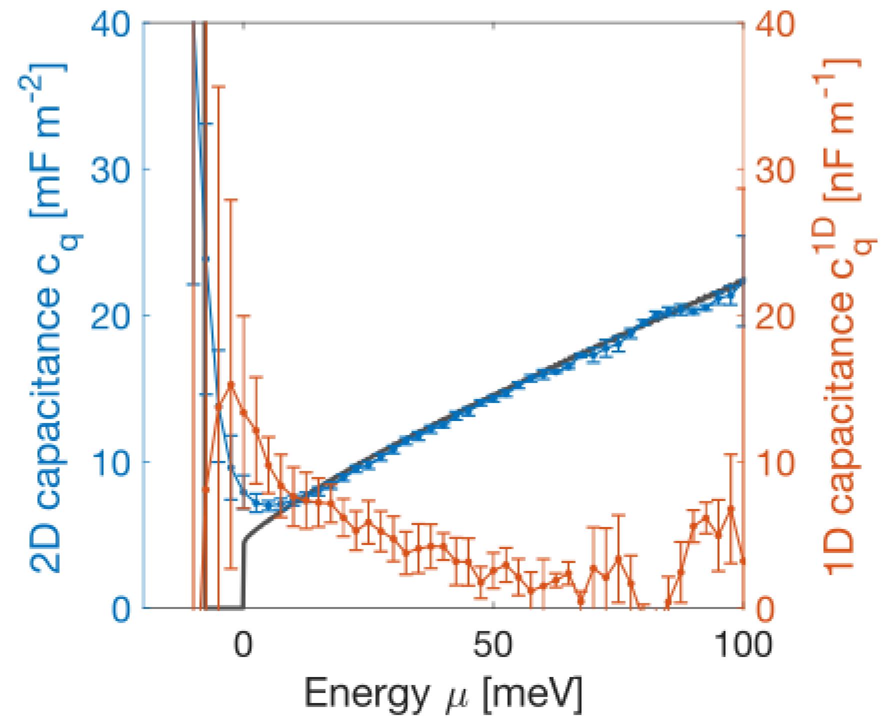
Trivial (5.8nm)



Topological A (10.6nm)



Topological B (8nm)



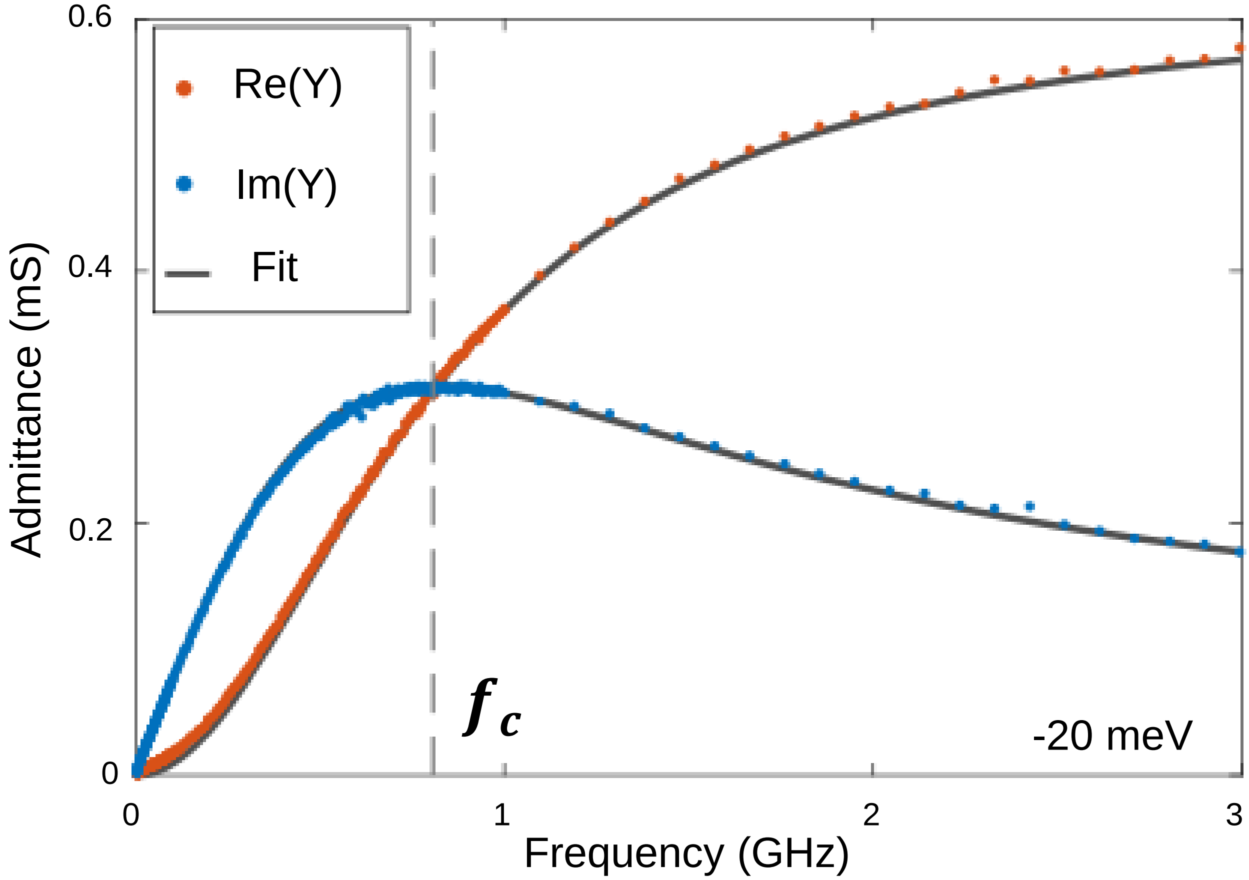
- 2D contribution: c_q^{2D} follows k.p predictions (even better than c_q) with smearing
- 1D contribution: c_q^{1D}
  - only in Topological samples
  - detected in gap and conduction band!
  - $c_q^{1D} \simeq$ 5-10 nF.m^{-1} very high! (in theory $c_q^{1D} = \frac{4e^2}{hv_f} \simeq 0.2$ nF.m^{-1})

→ **« Dressed » edge states**

High frequency mesurement : Overview

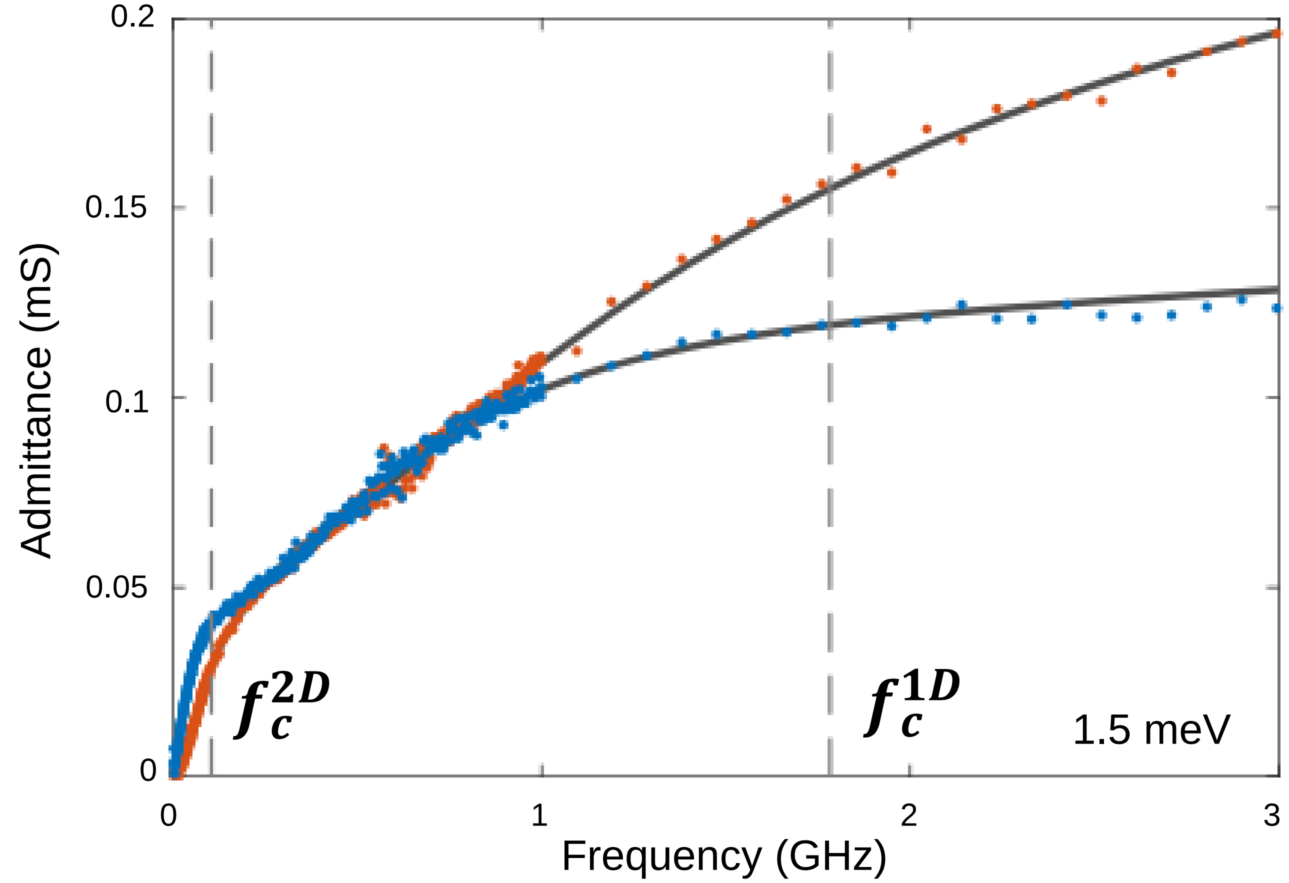
High frequency → evanescent waves

Far in the band: 1 mode transport (2D bulk)



- Cross over at $f_c = {}^{1}/_{2\pi R_t C_t}$
- 1 characteristic $R_t C_t$ time = 1 mode

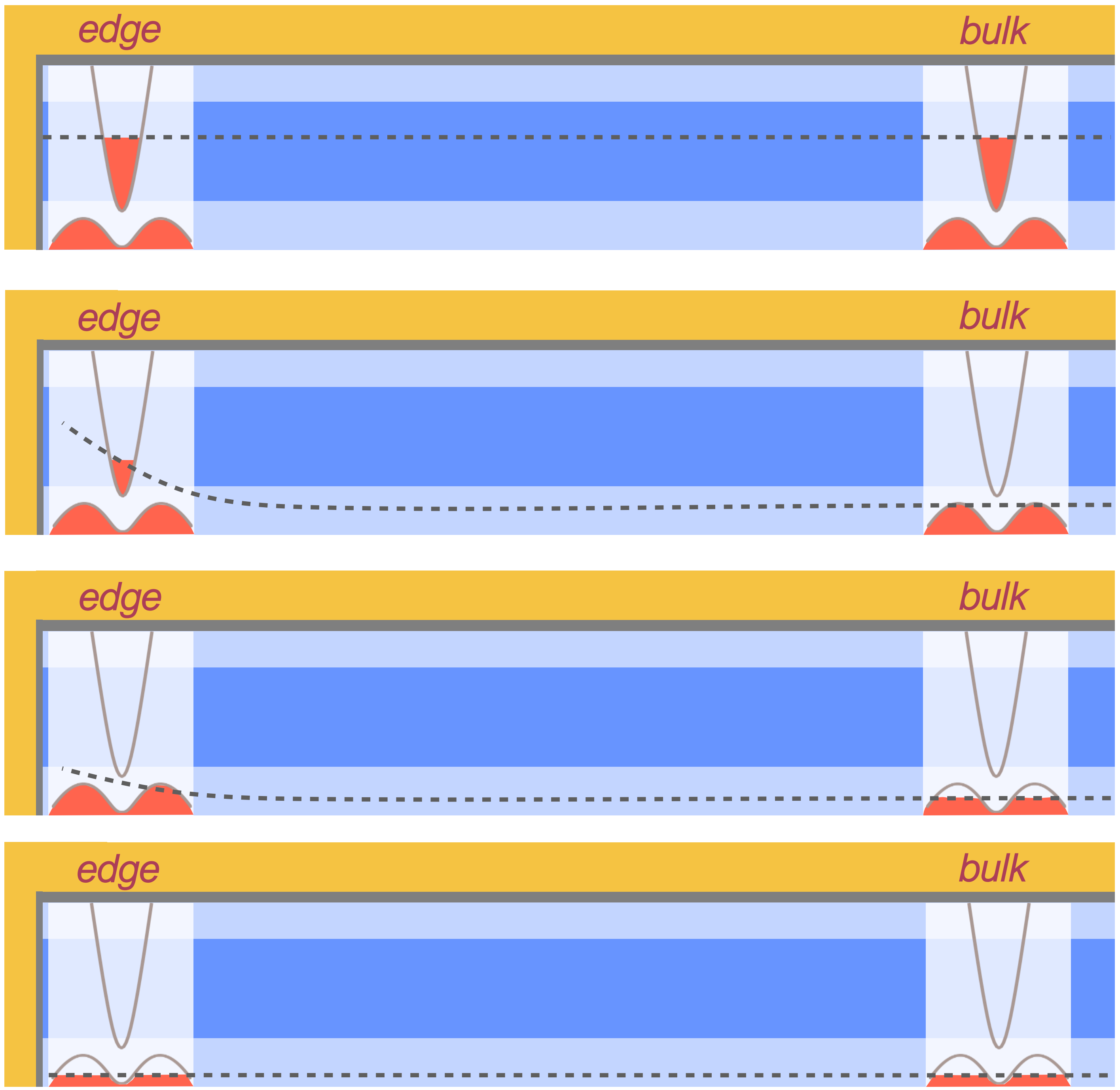
In the gap: 2 mode transport (2D bulk + 1D edges)



- 2 characteristic times = 2 modes
  - $R_t^{2D} C_t^{2D} = {}^{1}/_{2\pi f_c^{2D}}$: slow bulk mode
  - $R_t^{1D} C_t^{1D} = {}^{1}/_{2\pi f_c^{1D}}$: fast edge mode

The « dressed » edges states

Band bending effect



$V_g = 0$ V : homogeneously n-doped

$V_g = -0.3$ V : empty bulk (pinned to VB)
'dressed' edge states

$V_g = -0.5$ V : p-doped bulk
'clean' edge states

$V_g = -0.7$ V : homogeneously p-doped

Conclusion

- Length dependence show indeed 1D contribution existing only for topological samples
- Validated by 2-mode dynamic

But this supposed edge states are **very dense** compared to expectation $\mathbf{c_q^{1D} \simeq 10\ nF\ m^{-1}}$

→ New scenario : **dressed edge states** (electrostatic)
In agreement with results of M.R. Calvo et al.

Thank you !