SAND2022-2527C

Induced Superconducting Pairing in Integer Quantum Hall Edge Modes of InAs

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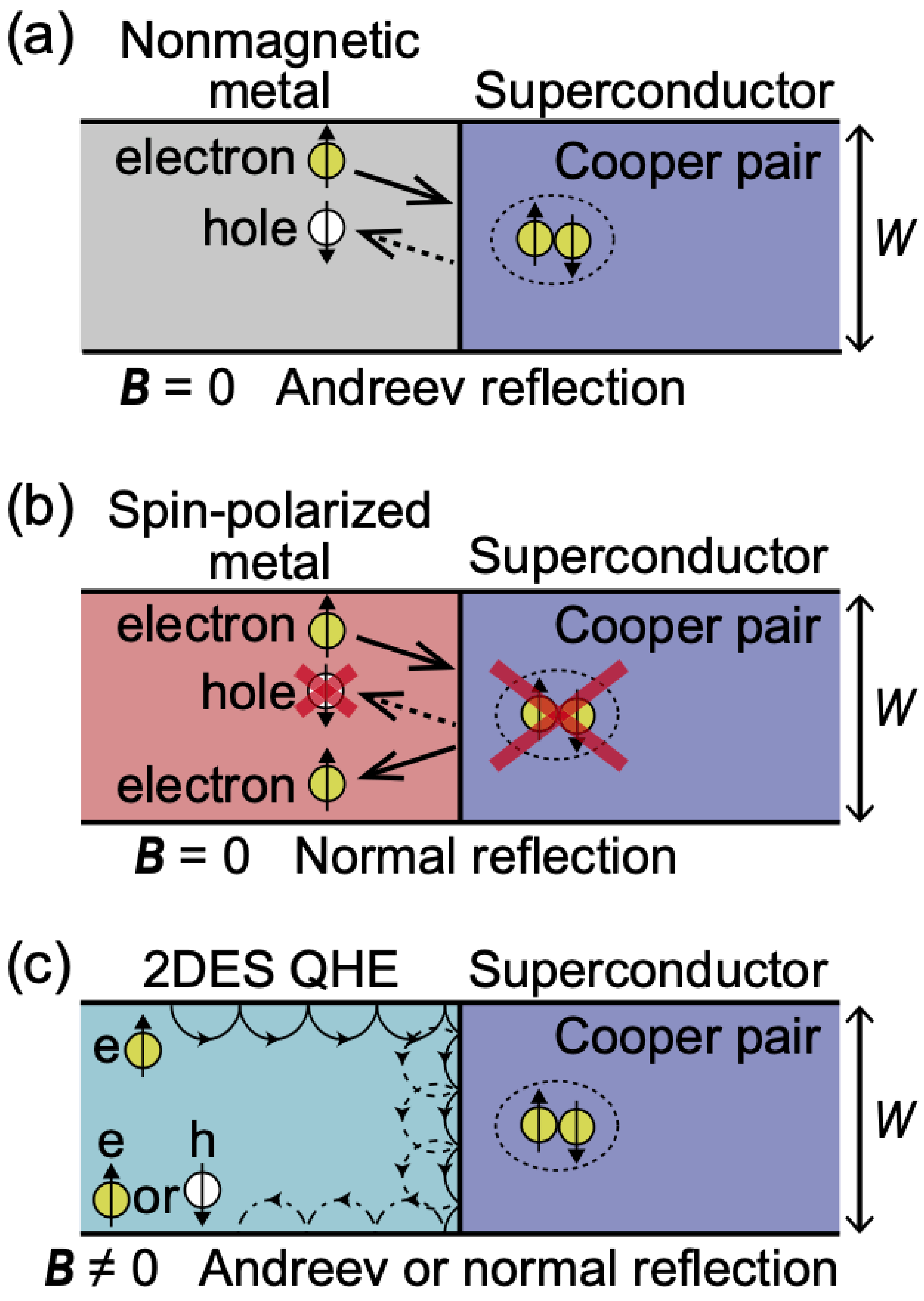
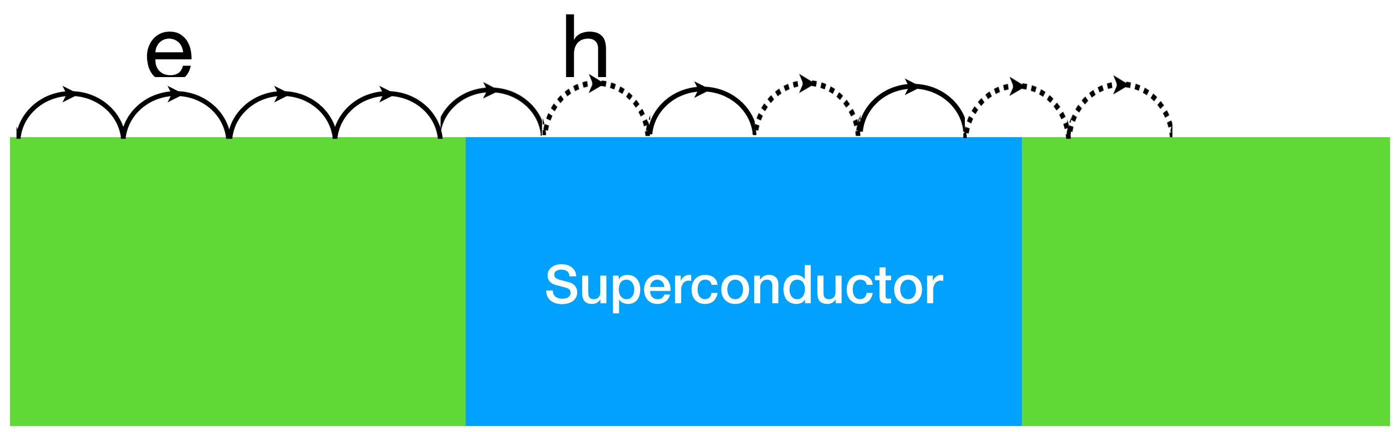
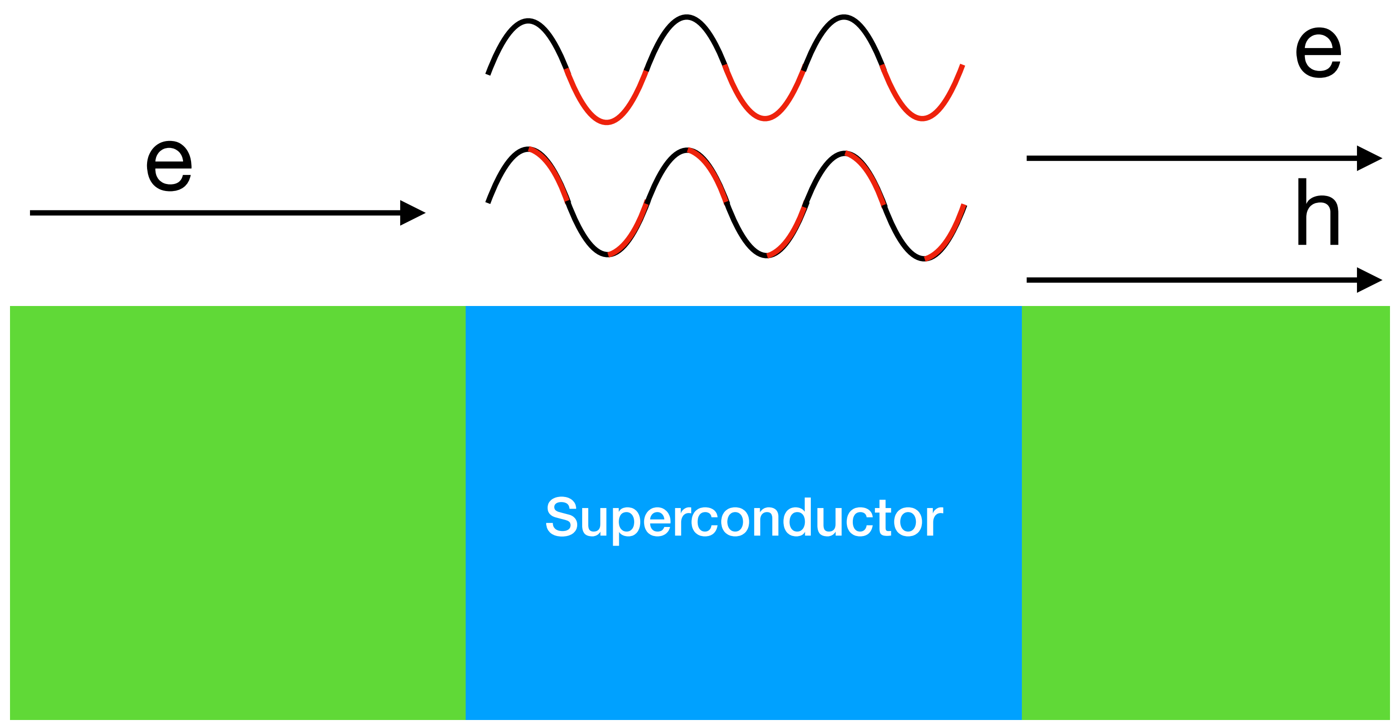
Motivation

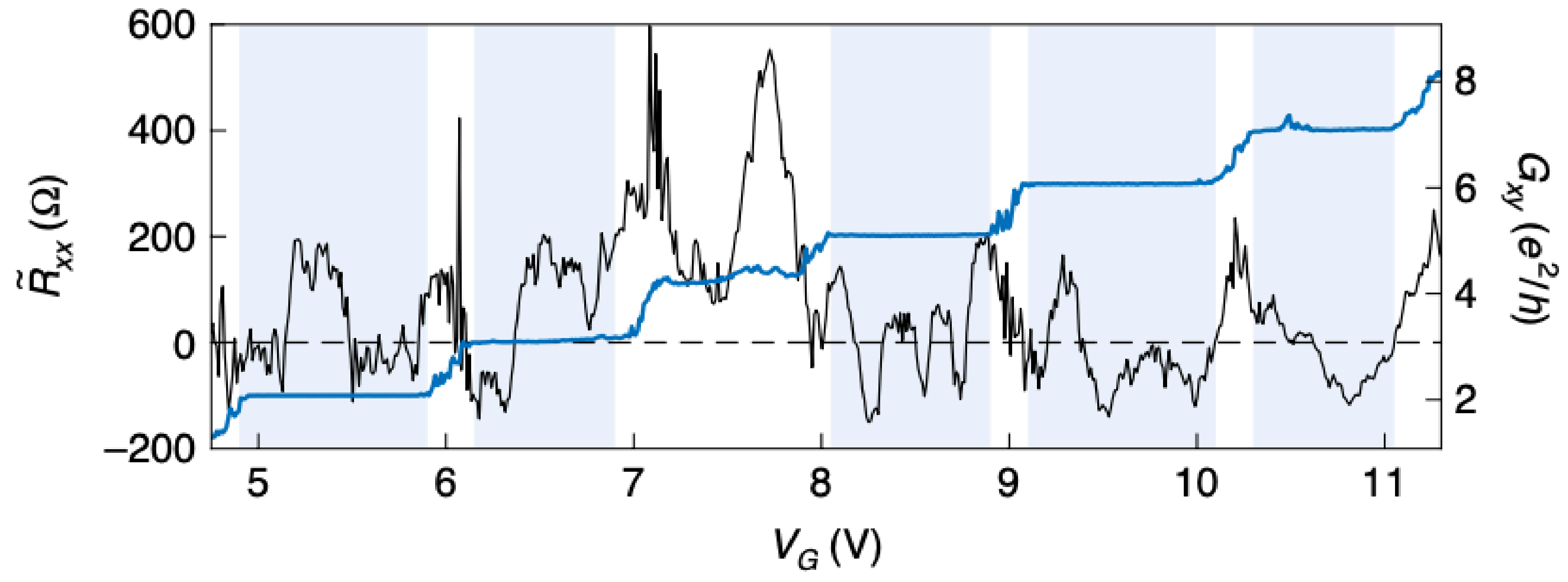




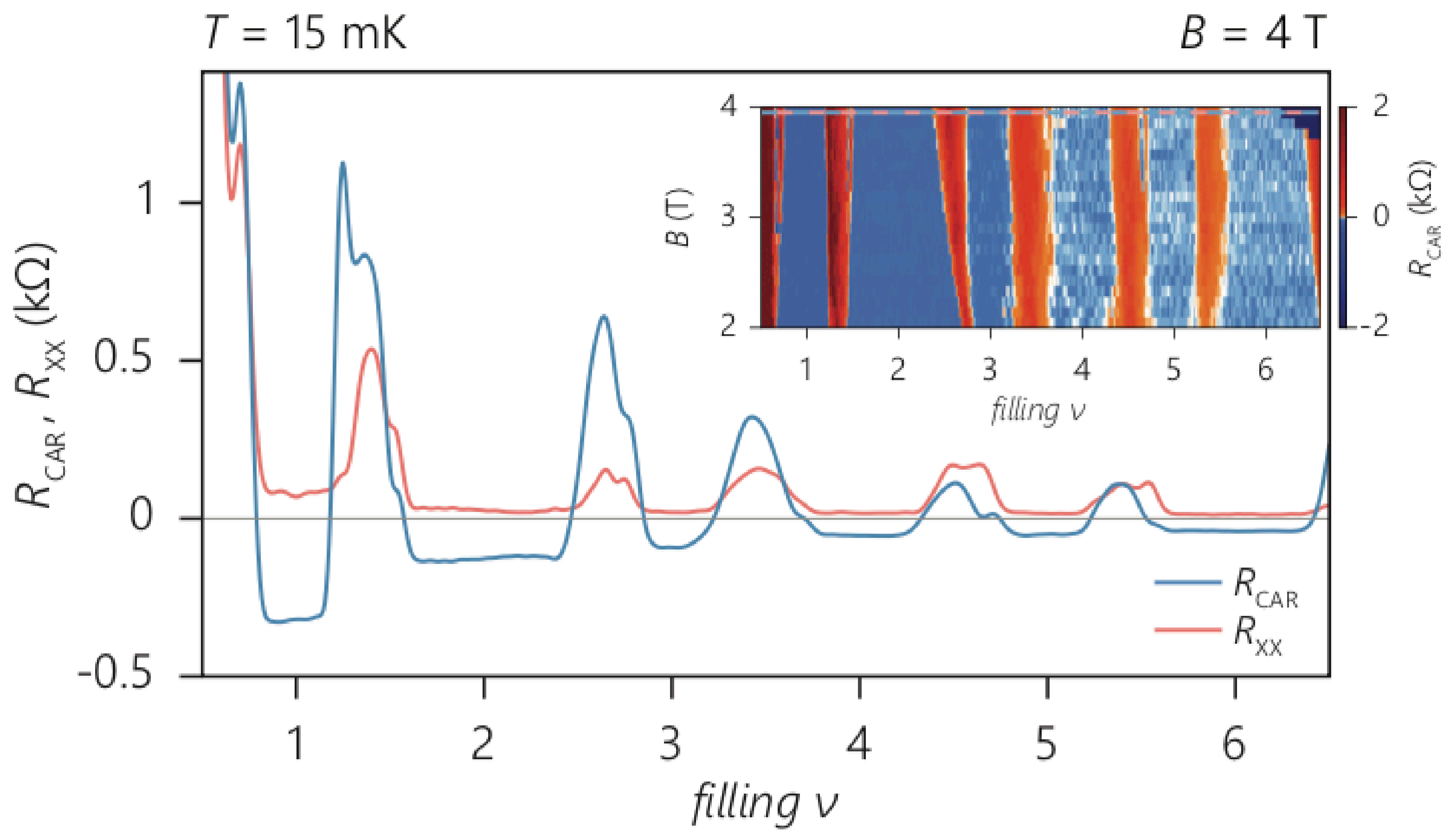
$$\Psi_e = a^*\Psi_+ + b^*\Psi_-$$

$$P_h = 4|\alpha|^2|\beta|^2 sin^2(\delta kL/2)$$





- Andreev reflection at the interface
- Chiral Andreev edge states
- Expected in longitudinal resistance:
  - Oscillations
  - Negative resistance

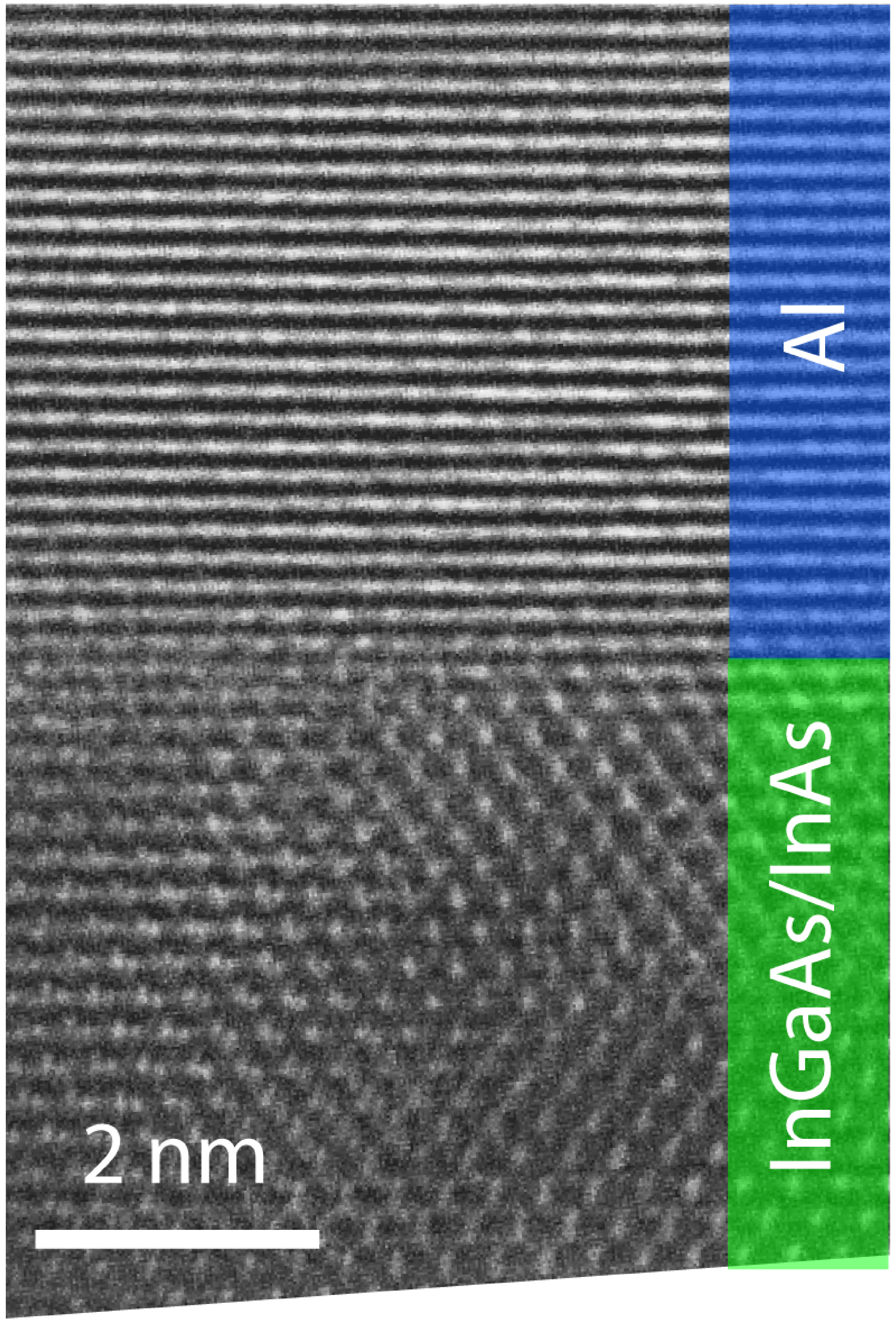


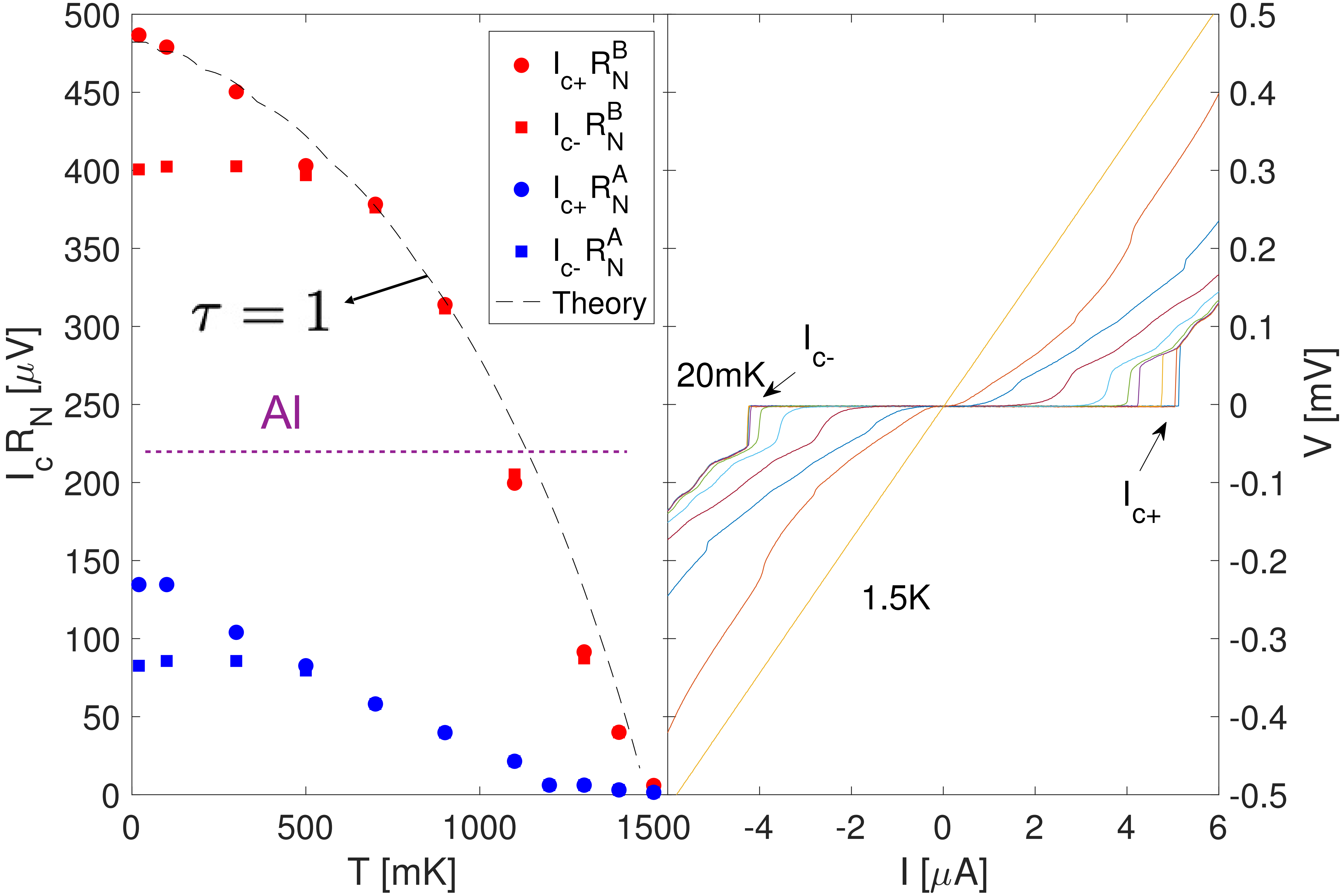
Y. Kozuka et al. JPS (2018)

L. Zhao et al. Nature Physics (2020)

Ö. Gül et al. arXiv:2009.07836 (2020)

Key ingredients: epitaxial contacts

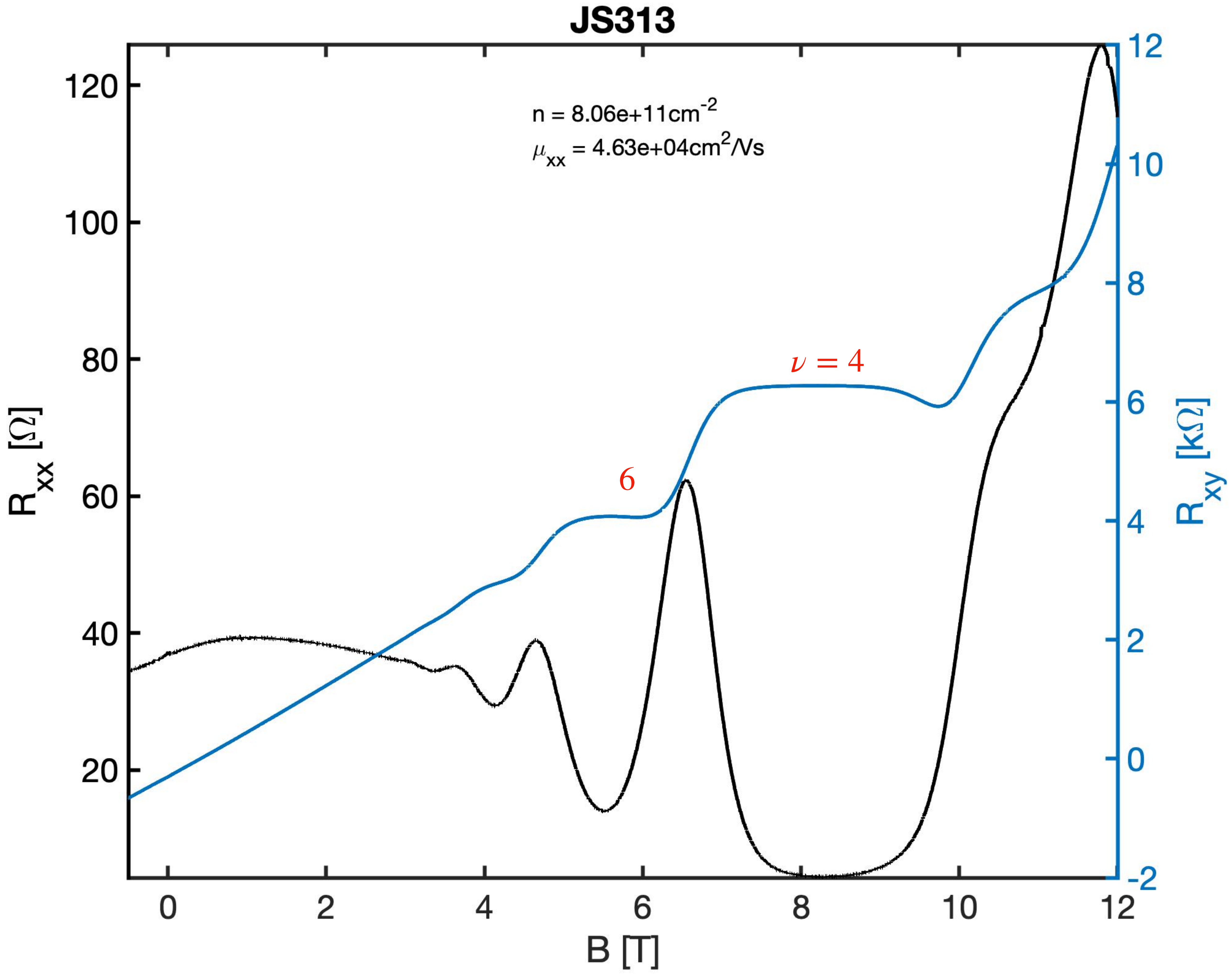


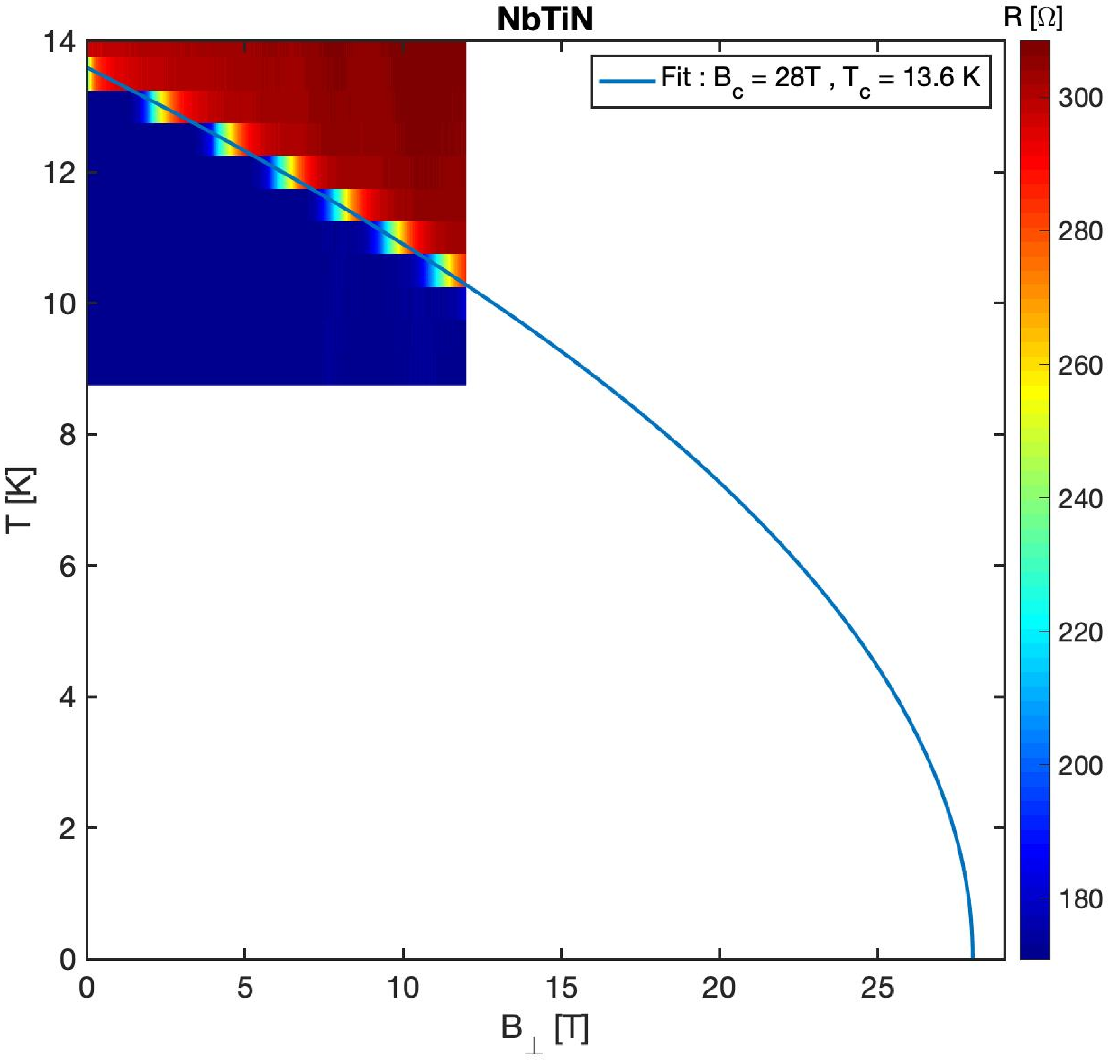


Yuan et al., PRB (2020)
Wickramasinghe, K. S. et al. APL (2018)

W. Mayer et al. APL (2019)
M. Dartiailh et al. Nature Comm. (2021)

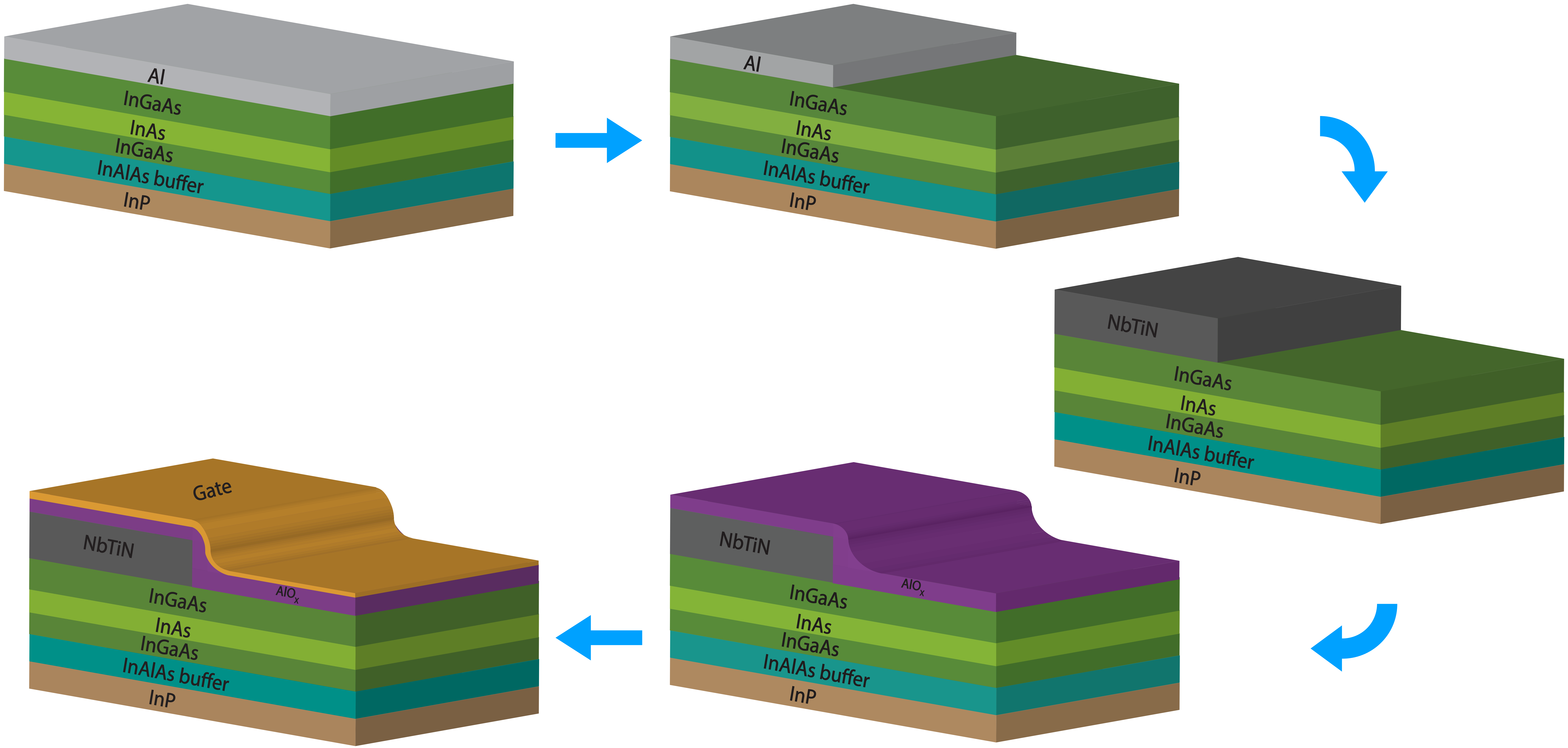
Individual ingredients





M. Hatefipour et al. arXiv:2108.08899 (2021)

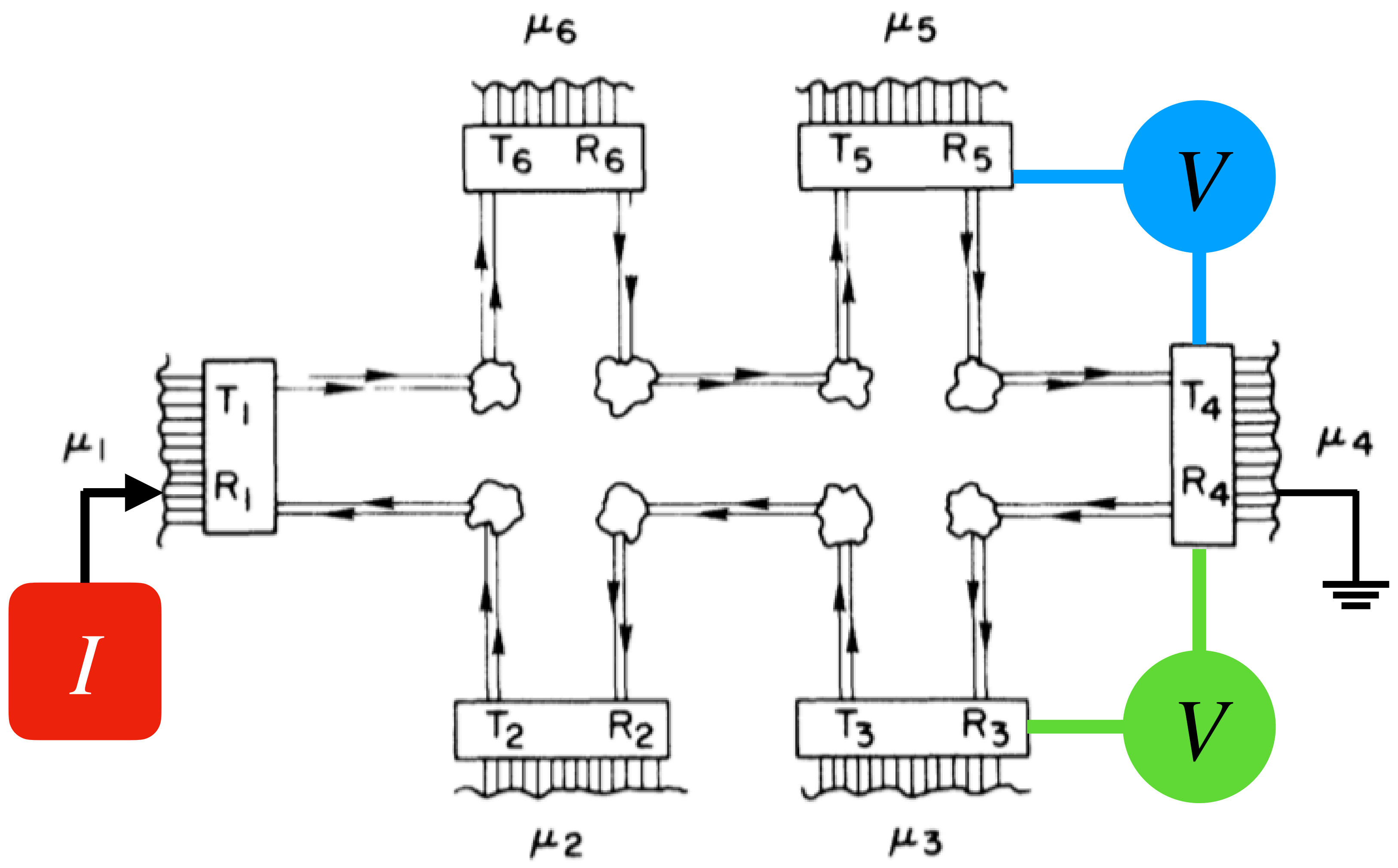
Device Fabrication



M. Hatefipour et al. arXiv:2108.08899 (2021)

False colored optical photo of the device

M. Hatefipour et al. arXiv:2108.08899 (2021)



$$\mathcal{R}_{14,54}=(\mu_5-\mu_4)/eI=(h/e^2)(1/T_4)$$

Quantum Hall setup

$$\mathcal{R}_{14,34}=(\mu_3-\mu_4)/eI=(h/e^2)(R_4/NT_4)$$

Longitudinal setup

Where $R_4 + T_4 = N$, N is filling factor

Ideal contact

$R_4 = 0, T_4 = N$ $\Rightarrow$ $R_{14,54} = \dfrac{h}{Ne^2} = R_{Hall}$ $\quad R_{14,34} = 0$

M. Büttiker, PRB(1988)

Büttiker Formalism Modification for Andreev Reflection (AR)

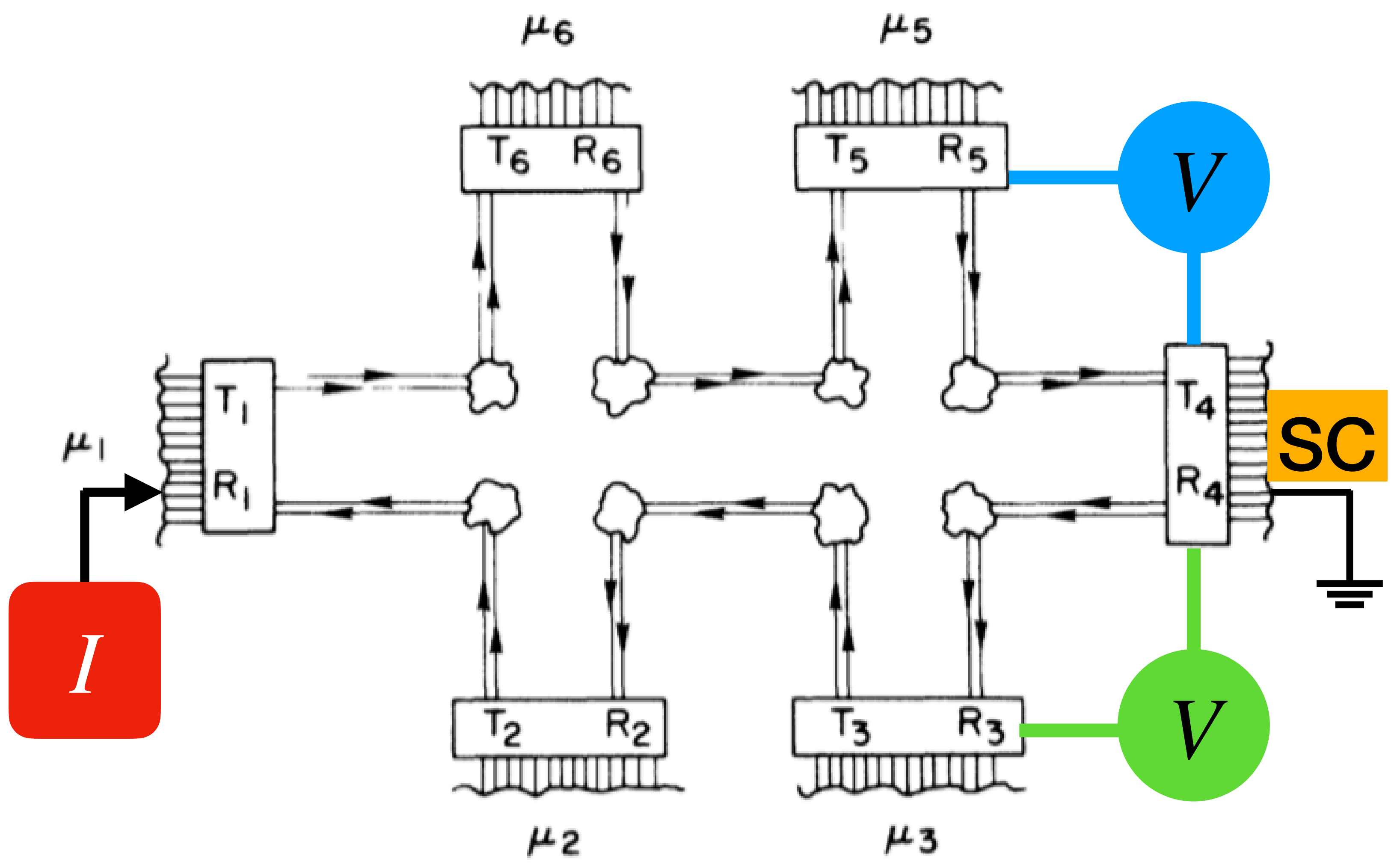
Normal contact : $R + T = 1$

Superconducting contact : $A + T + T_{edge} = 1$

A probability of electron-hole conversion

T probability for a single electron tunneling into the SC

T_{edge} probability of an incident electron to scatter to the downstream edge



$$\begin{pmatrix} I_5 \\ I_s \\ I_3 \\ I_1 \end{pmatrix} = \frac{\nu e^2}{h} \begin{pmatrix} 1 & 0 & 0 & -1 \\ -\alpha & \alpha & 0 & 0 \\ \alpha - 1 & -\alpha & 1 & 0 \\ 0 & 0 & -1 & 1 \end{pmatrix} \begin{pmatrix} V_5 \\ V_s \\ V_3 \\ V_1 \end{pmatrix}$$

$$\boxed{\alpha = 2A + T}$$

$$I_1 = I \,, I_{sc} = -I \rightarrow (V_5 - V_s)/I = \frac{h}{e^2\nu}\frac{1}{\alpha} = R_{5-s}$$

$$(V_3 - V_s)/I = \frac{h}{e^2\nu}\frac{1-\alpha}{\alpha} = R_{3-s}$$

$$R_{5-s} = \frac{h}{e^2\nu}\frac{1}{\alpha} = R_U$$

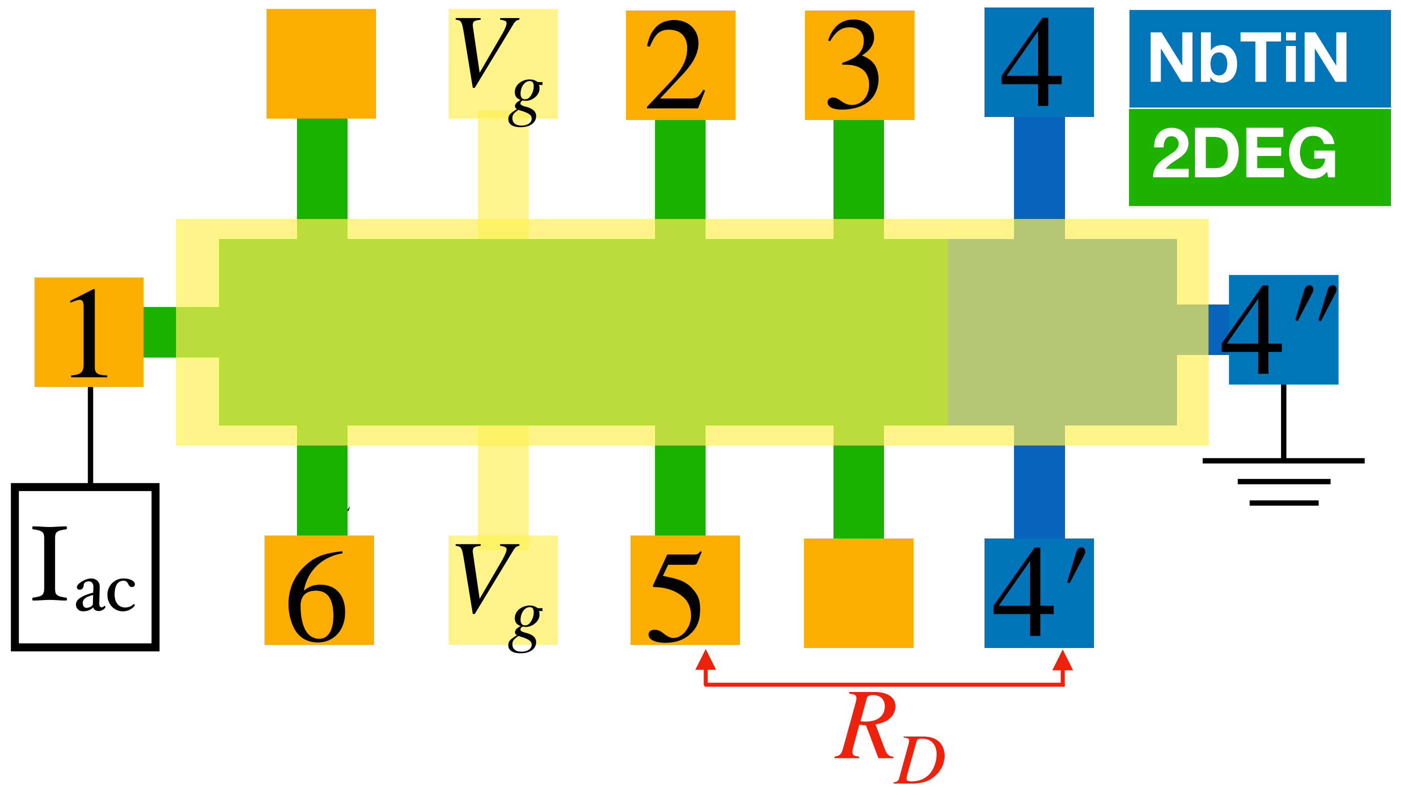
Quantum Hall setup

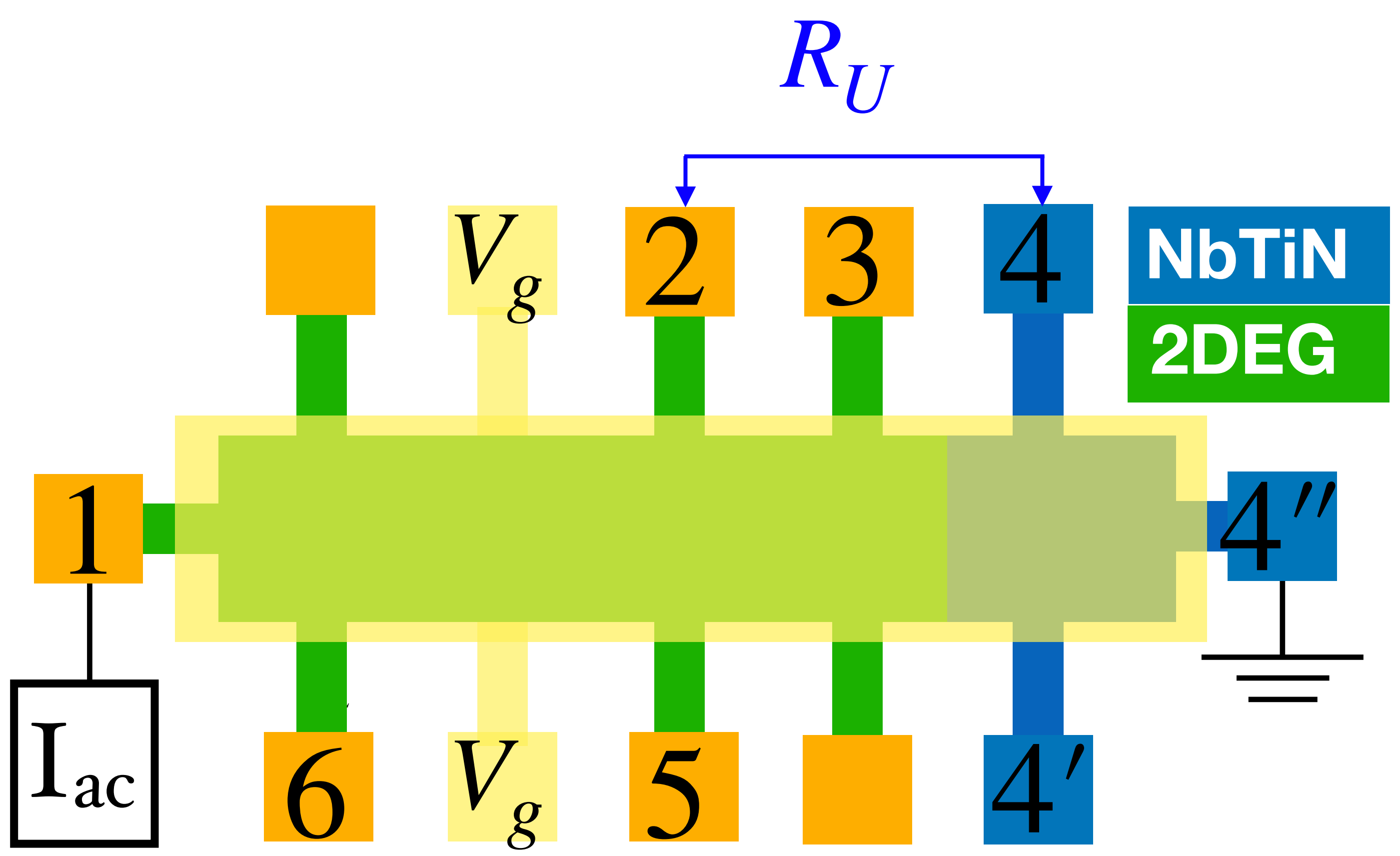
$$R_{3-s} = \frac{h}{e^2\nu}(\frac{1}{\alpha} - 1) = R_D$$

Longitudinal setup

M. Büttiker, PRB(1988)

M. Hatefipour et al. arXiv:2108.08899 (2021)





$$R_D = \frac{h}{e^2\nu}\left(\frac{1}{\alpha} - 1\right)$$

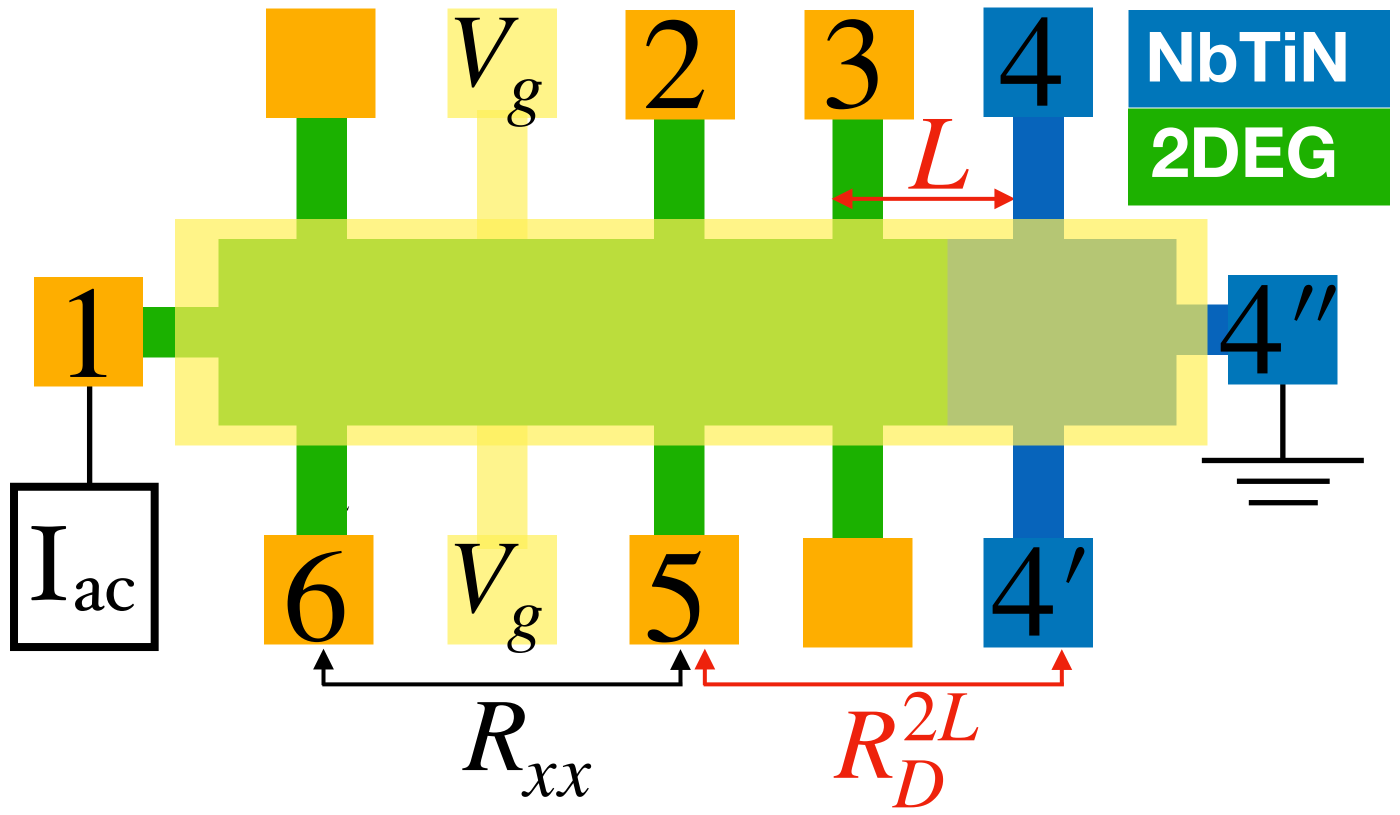
$$\alpha = 2A + T$$

$$R_U = \frac{h}{e^2\nu}\frac{1}{\alpha}$$

Ideal case: $\alpha = 2$	➡	$R_D = -\dfrac{h}{2\nu e^2}$	$R_U = \dfrac{h}{2\nu e^2}$
non-Ideal case:	If $\exists A : 1 < \alpha < 2$ ➡	$-\dfrac{h}{2\nu e^2} < R_D < 0$	$\dfrac{h}{2\nu e^2} < R_U < \dfrac{h}{\nu e^2}$

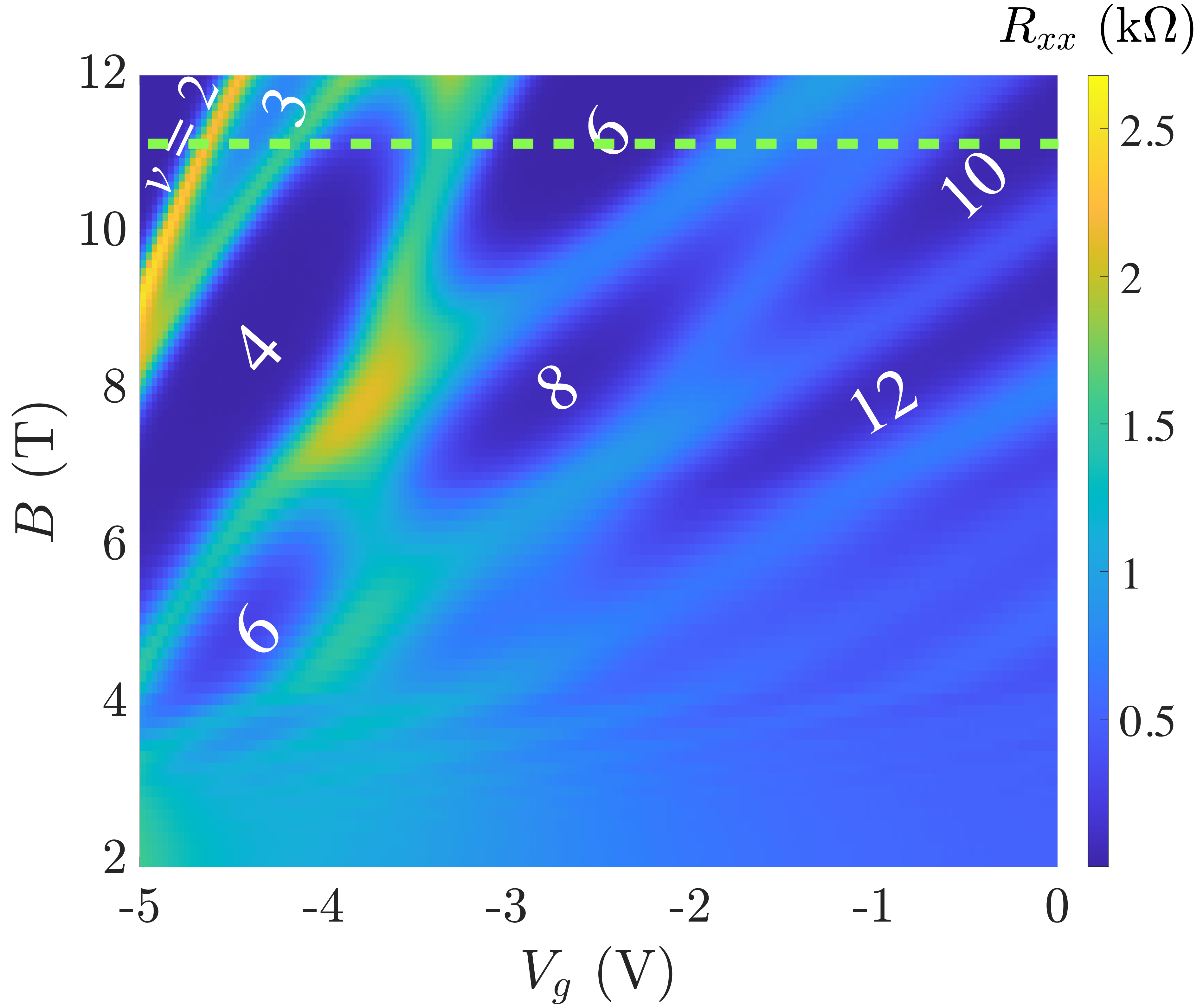
M. Hatefipour et al. arXiv:2108.08899 (2021)

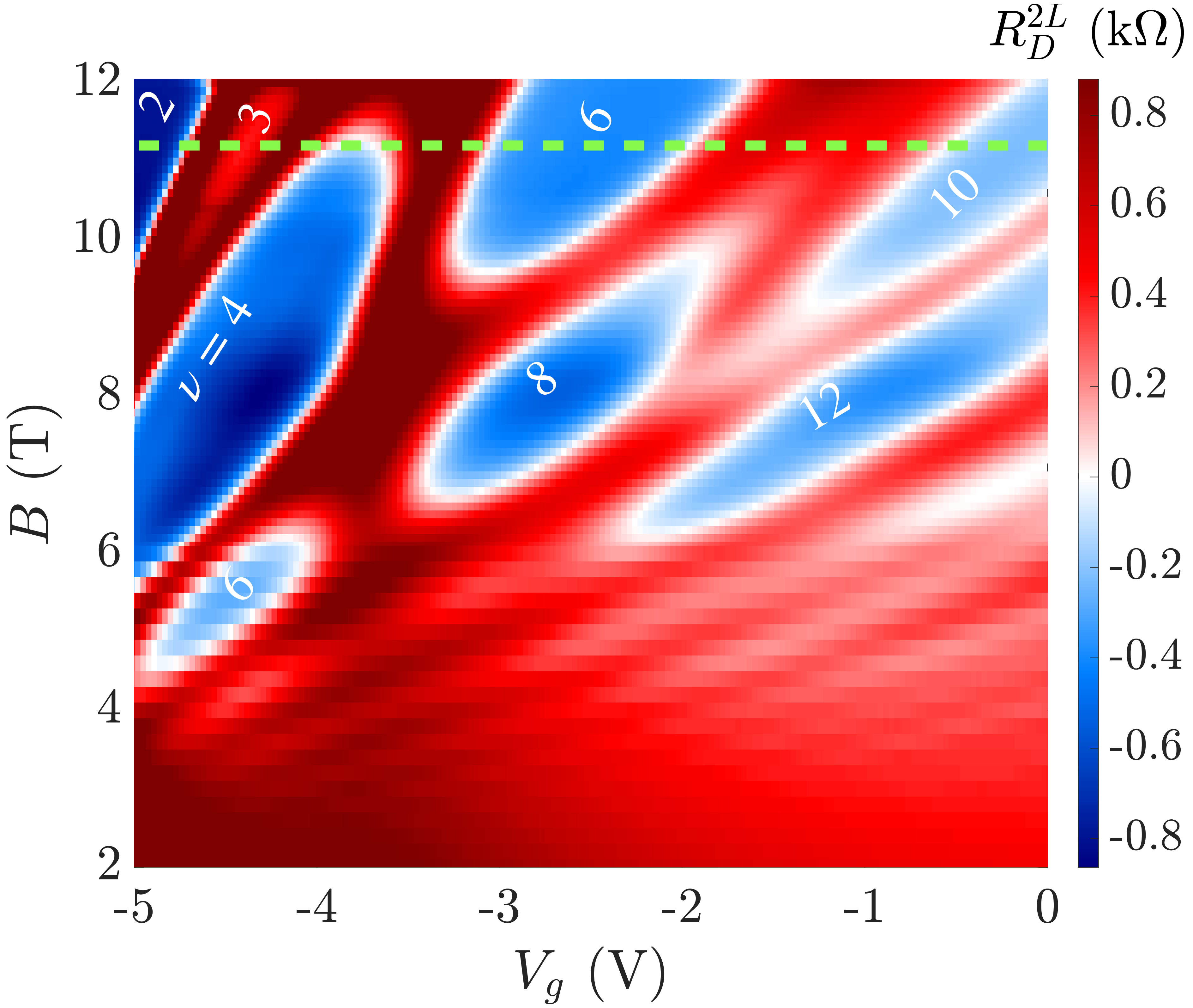
QH measurement / Down stream measurements



$$\alpha = 2A + T$$

$$R_D = \frac{h}{e^2\nu}\left(\frac{1}{\alpha} - 1\right)$$

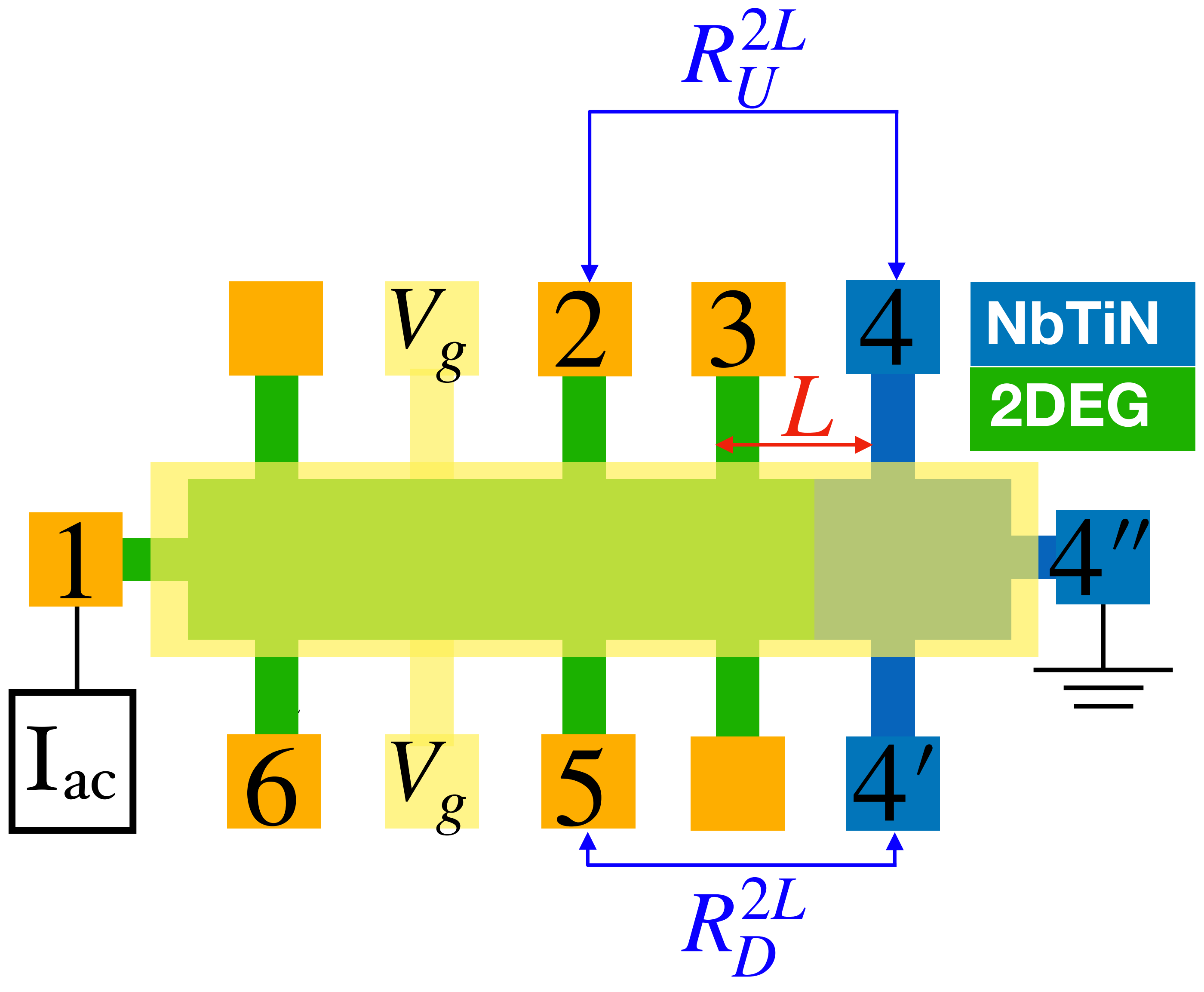


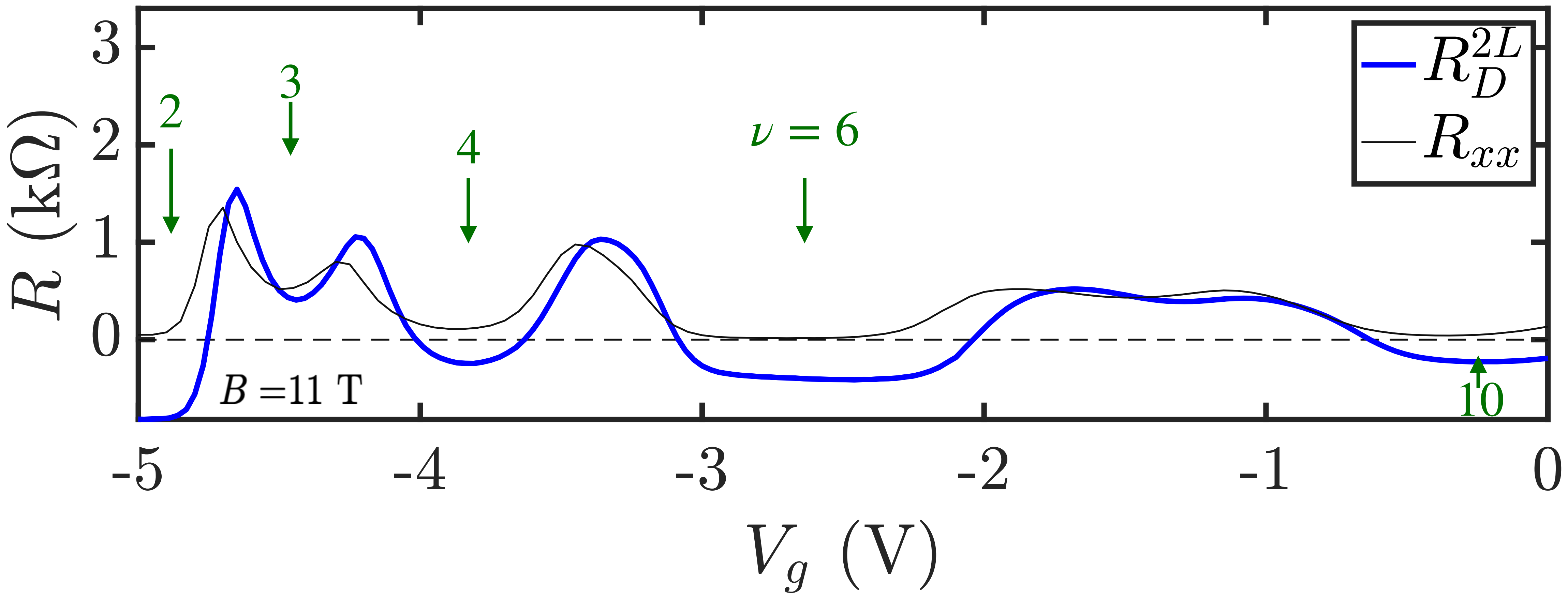


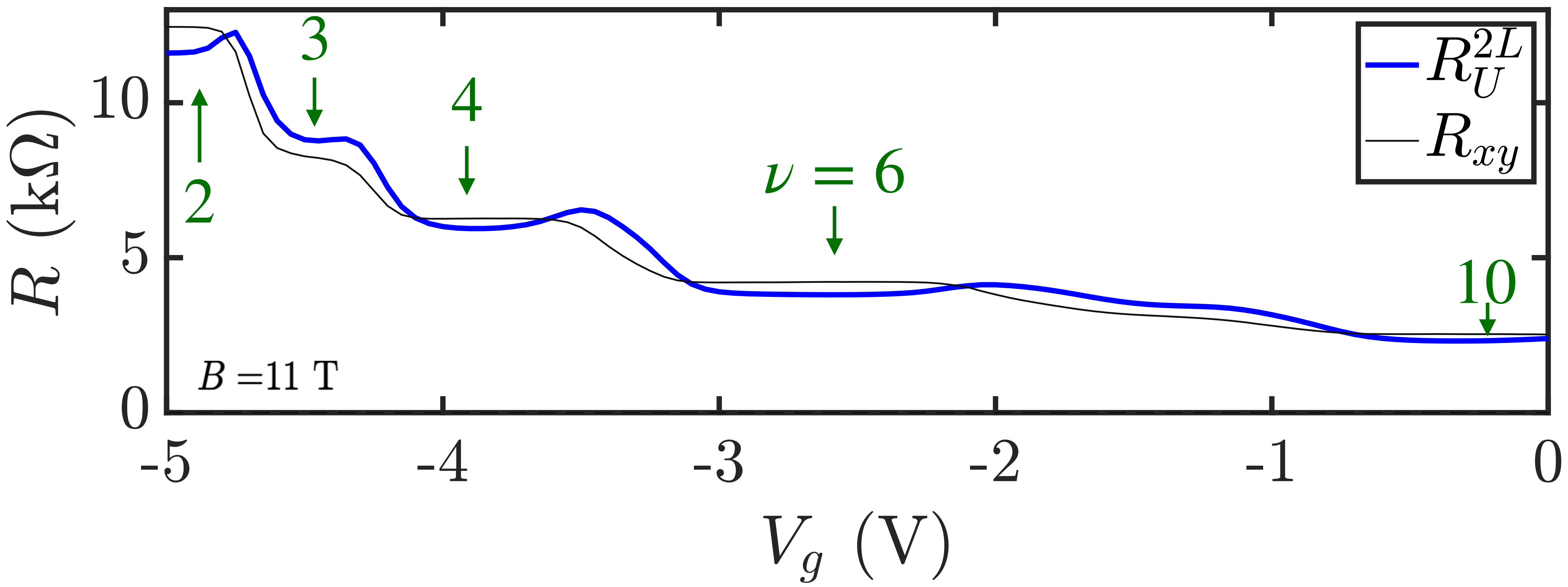
M. Büttiker, PRB(1988)

M. Hatefipour et al. arXiv:2108.08899 (2021)

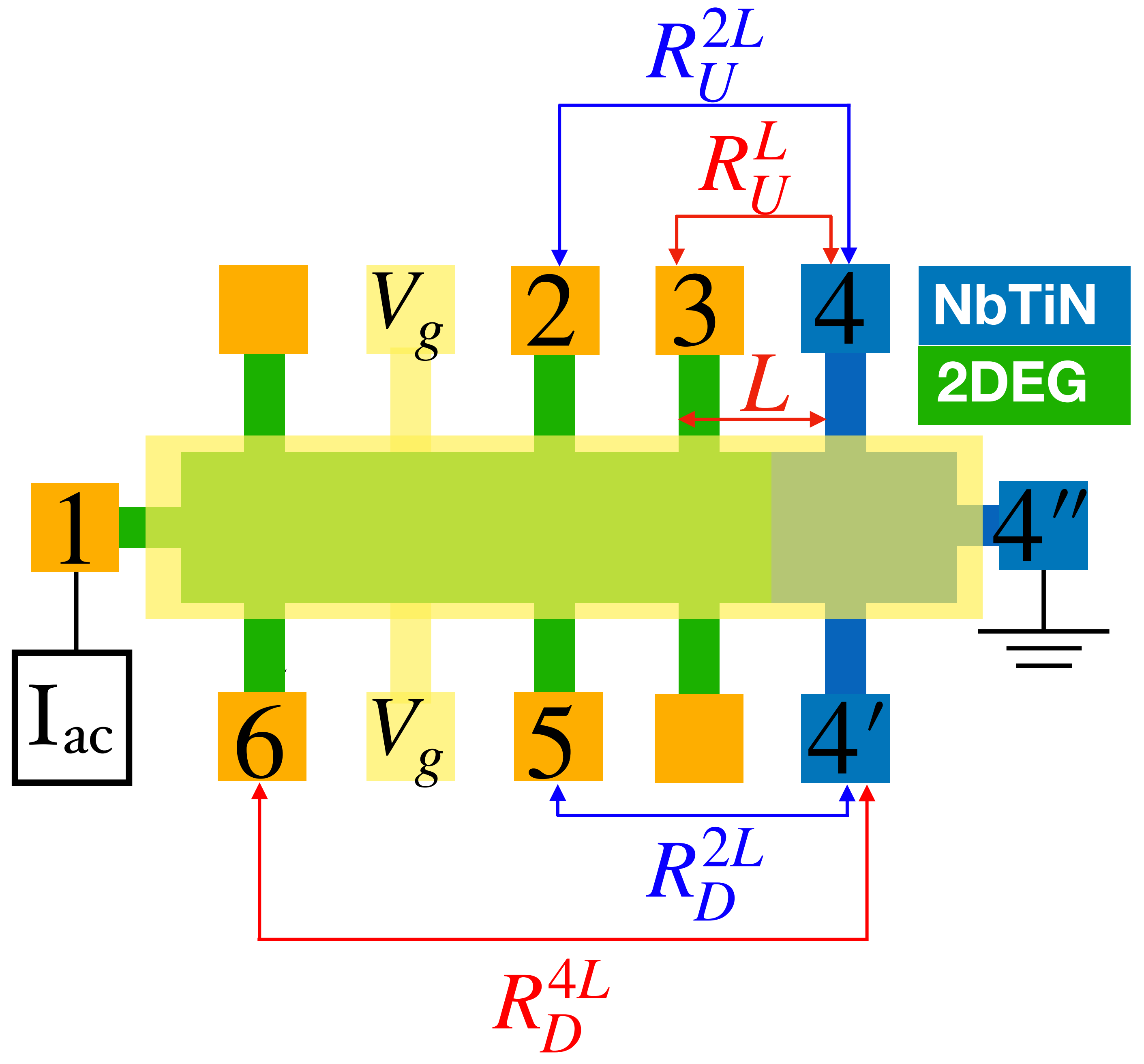
Down/up streams measurements

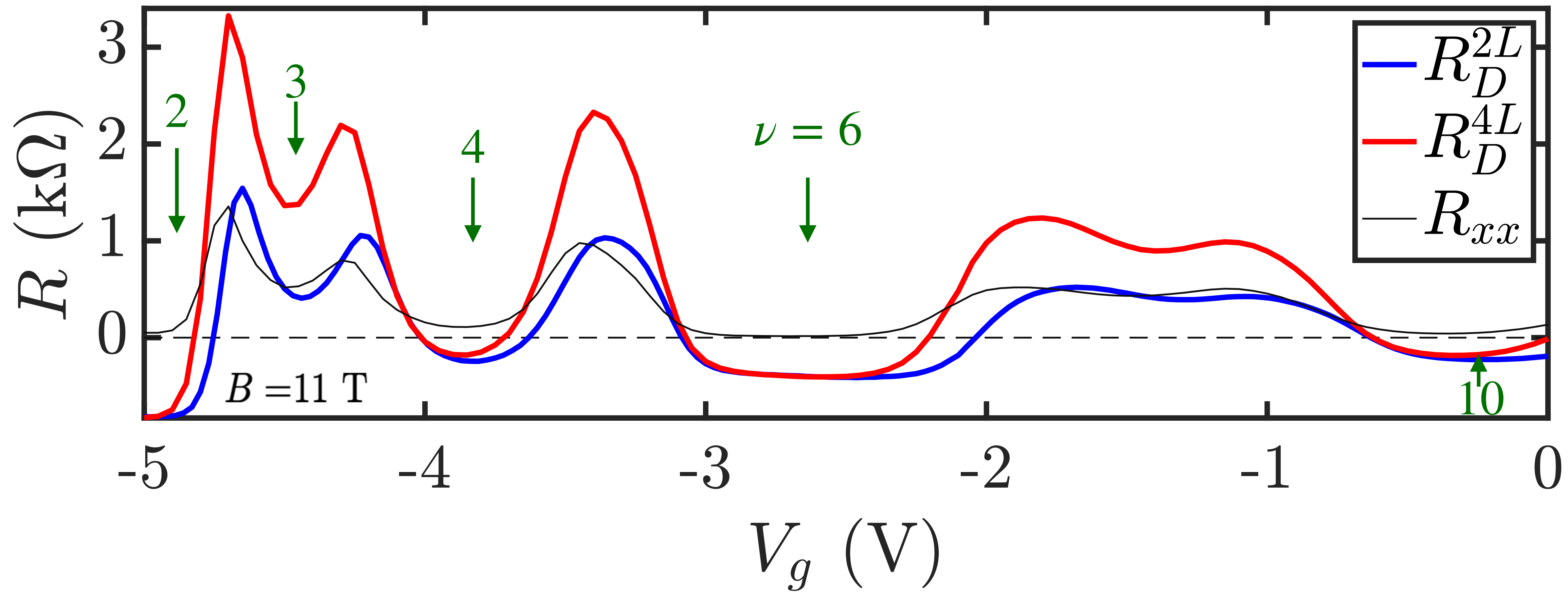


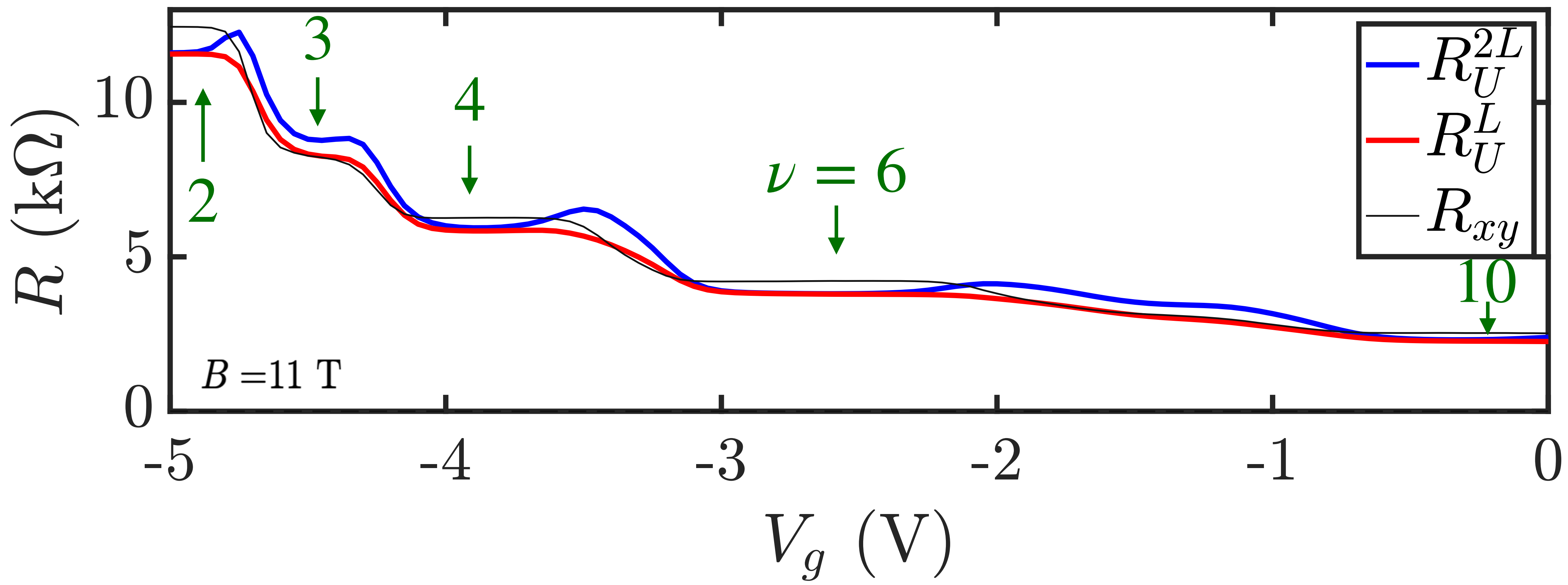




Down/up streams measurements







M. Büttiker, PRB(1988)

M. Hatefipour et al. arXiv:2108.08899 (2021)

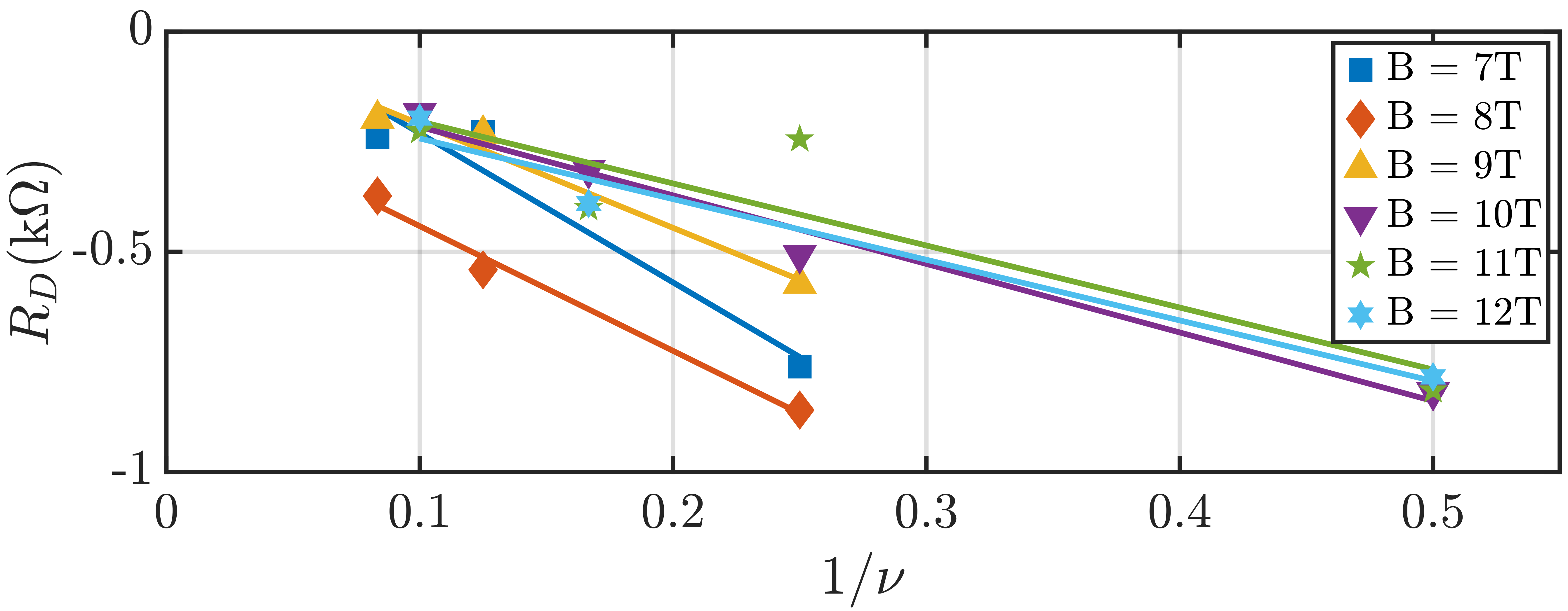
Down/up streams measurements

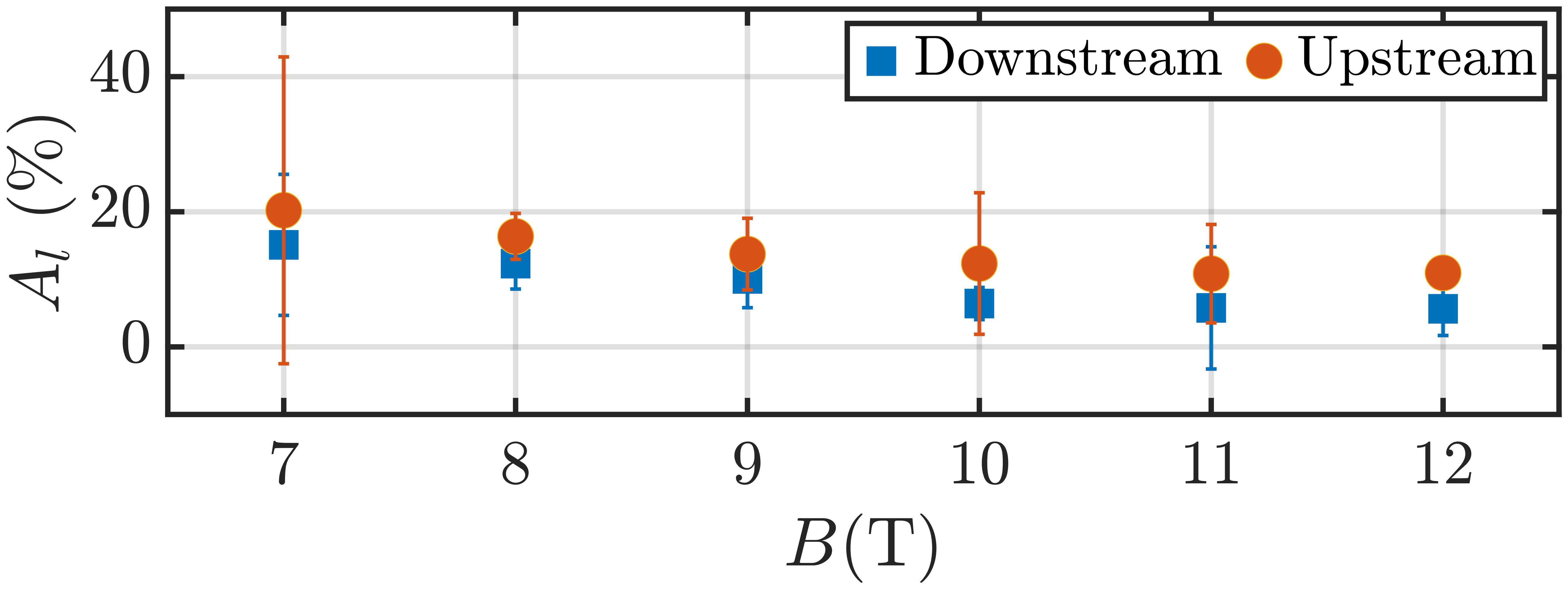
$$R_D = \frac{h}{e^2\nu}\left(\frac{1}{\alpha} - 1\right)$$

$$A + T + T_{edge} = 1$$

$$\alpha = 2A + T$$

$$A = \alpha - 1 + T_{edge}$$



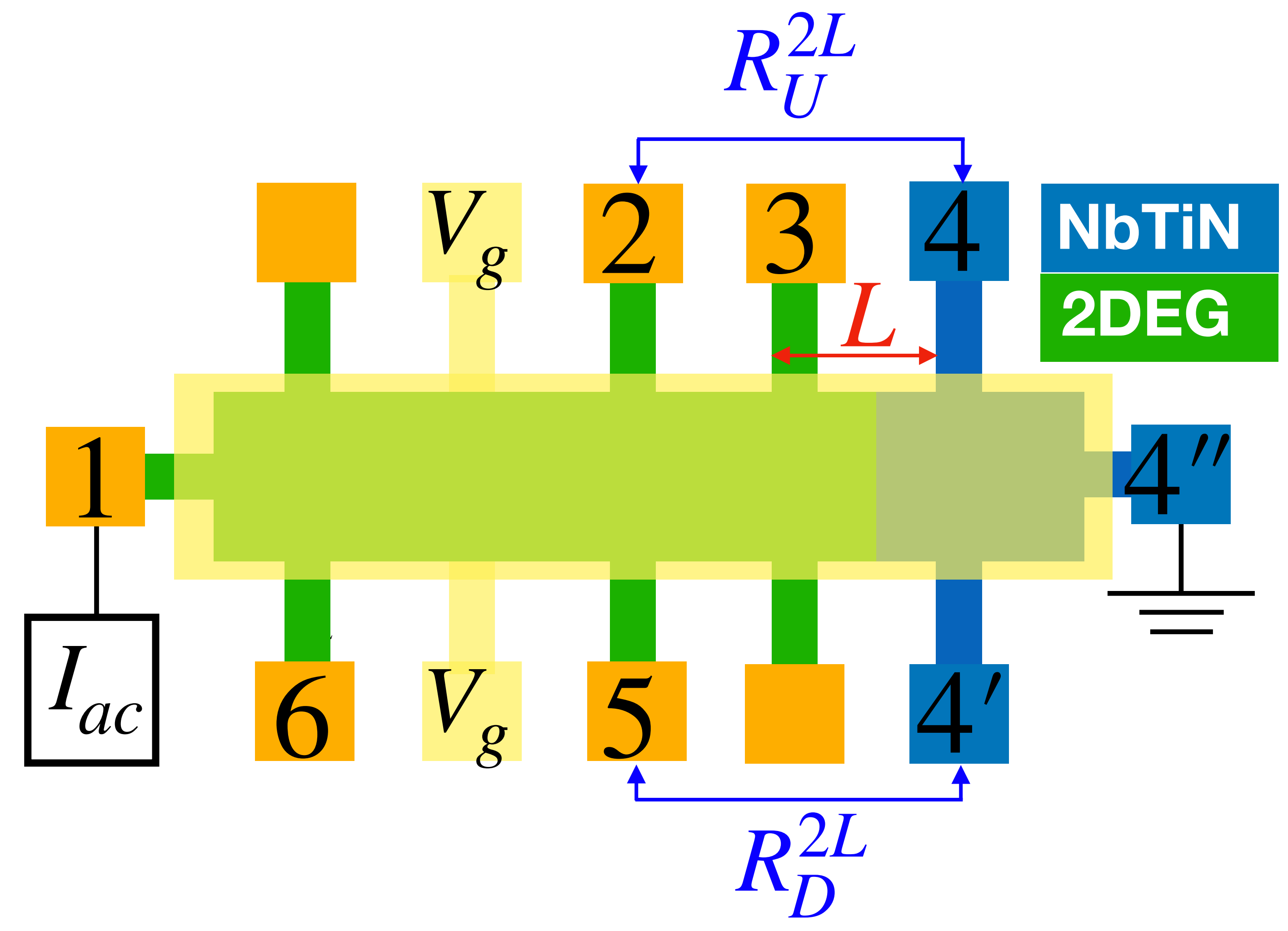


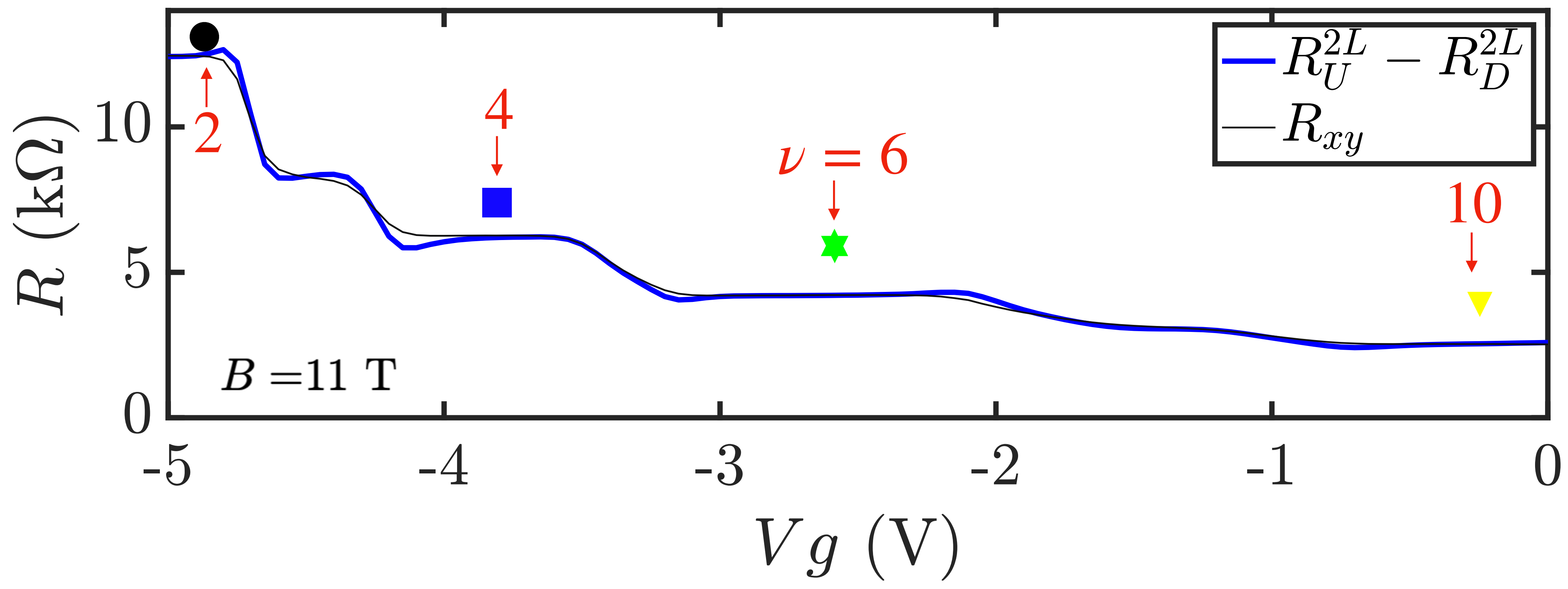
M. Büttiker, PRB(1988)

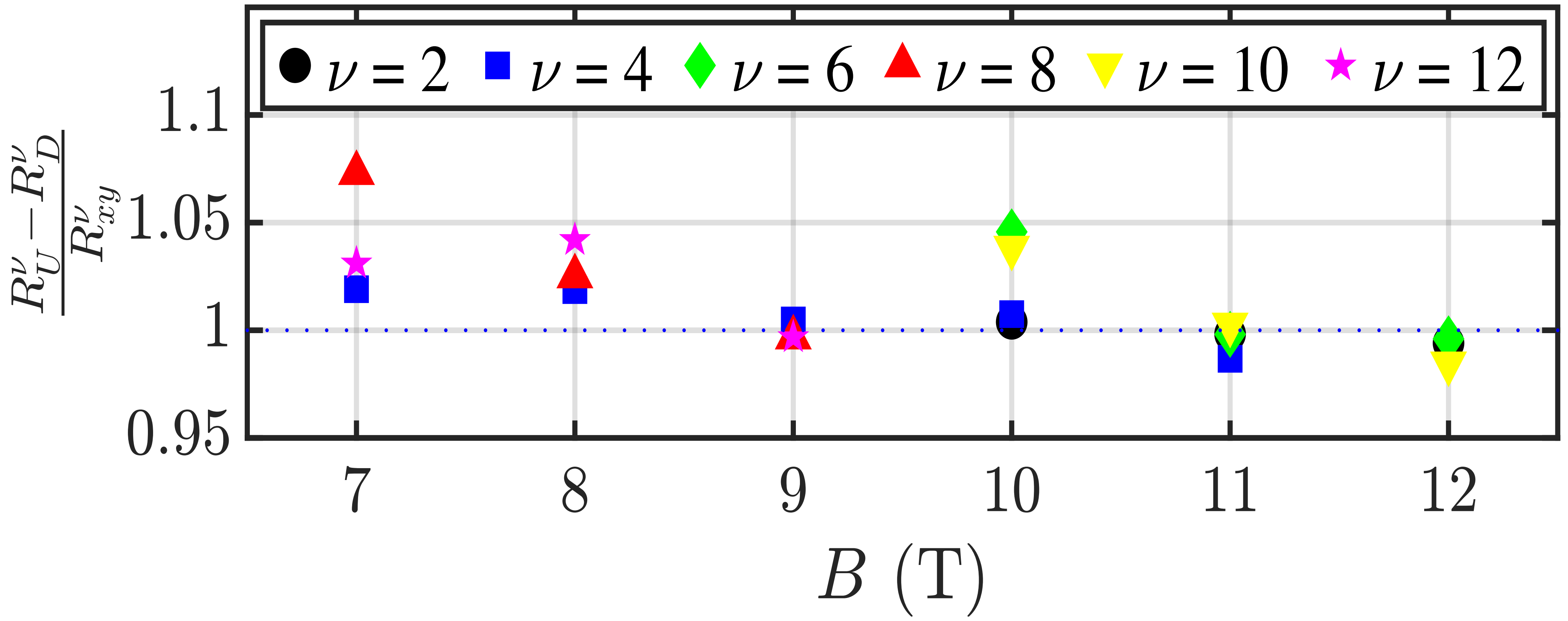
M. Hatefipour et al. arXiv:2108.08899 (2021)

Down/up streams measurements

$$R_U - R_D = \frac{h}{e^2\nu}\frac{1}{\alpha} - \frac{h}{e^2\nu}\left(\frac{1}{\alpha} - 1\right) = \frac{h}{e^2\nu} = R_{xy}$$



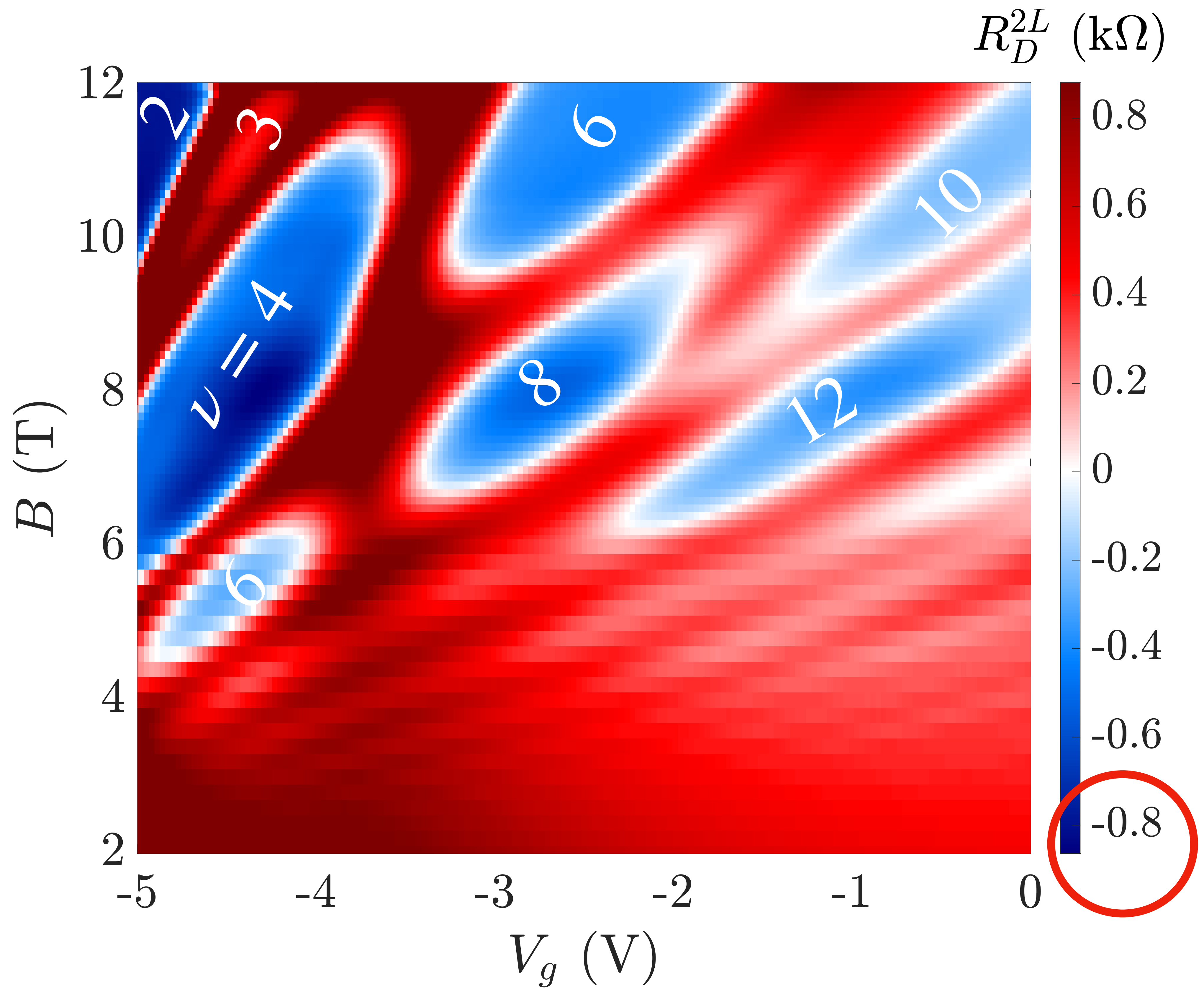




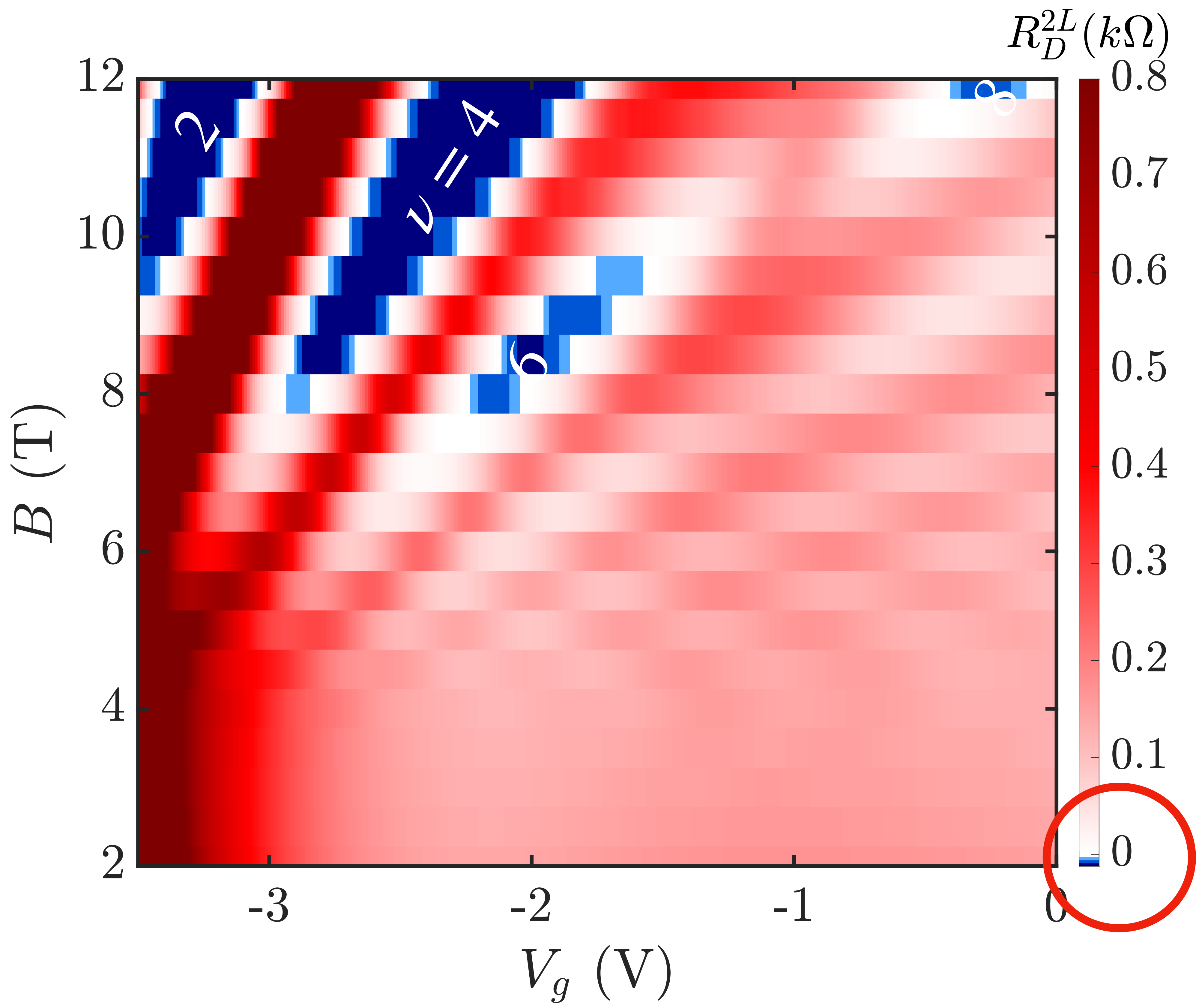
M. Büttiker, PRB(1988)

M. Hatefipour et al. arXiv:2108.08899 (2021)

Interface transparency/cleanness



Proper interface cleaning before NbTiN deposition

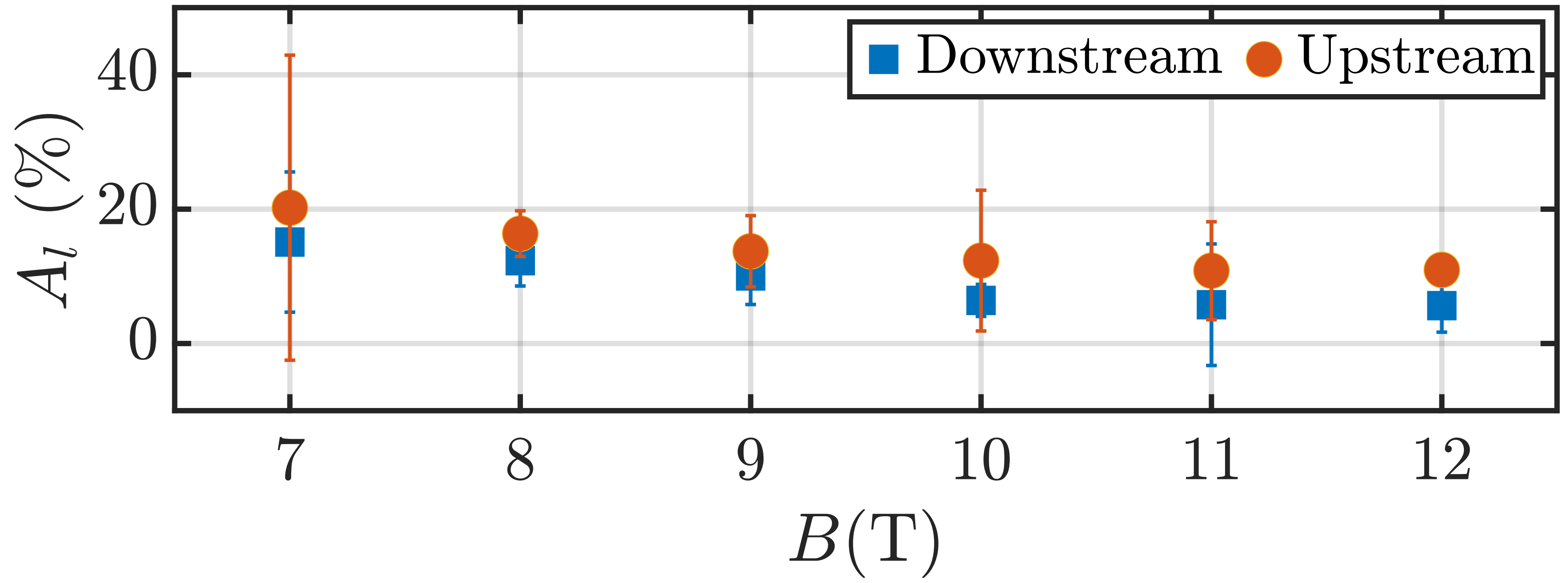


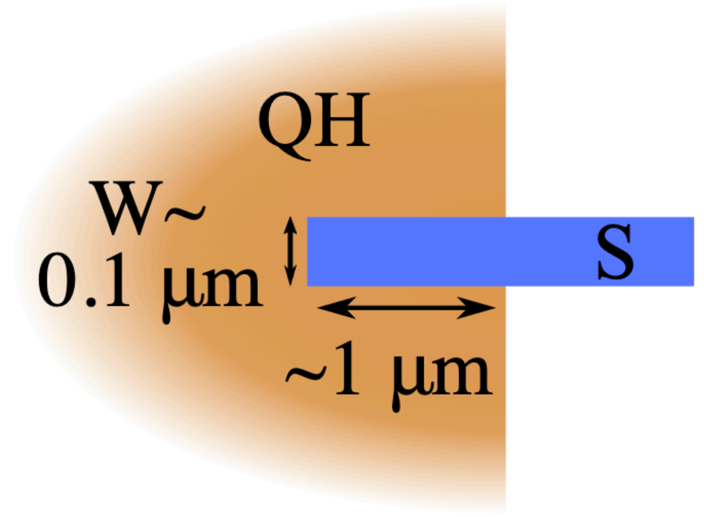
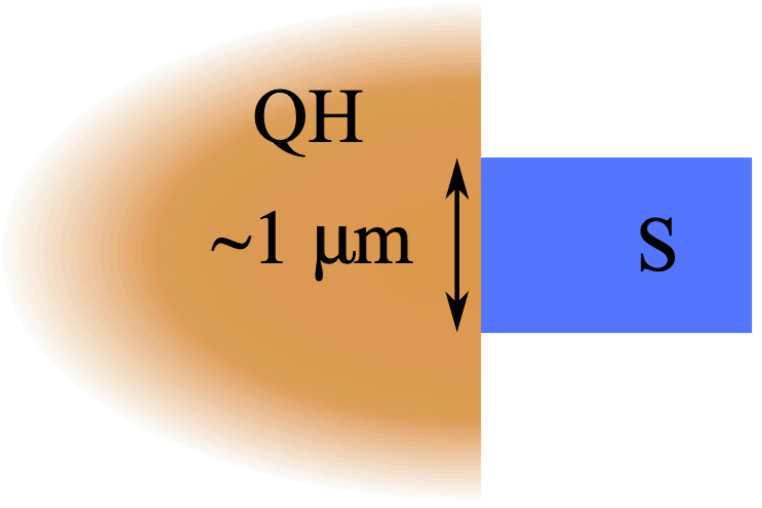
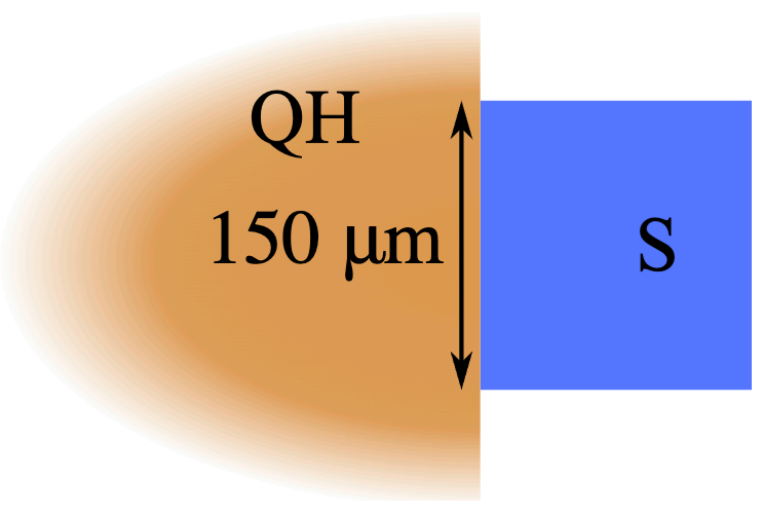
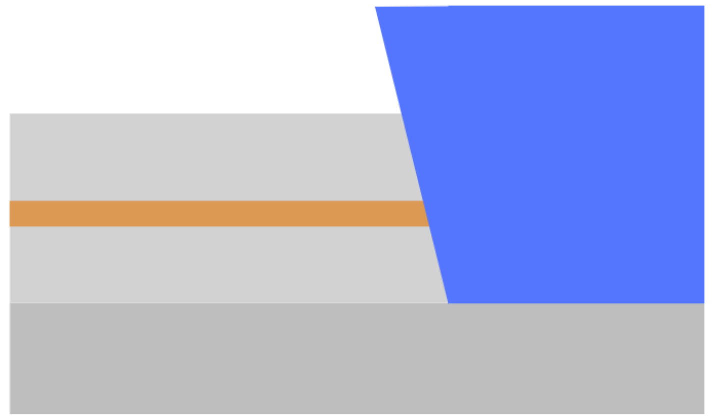
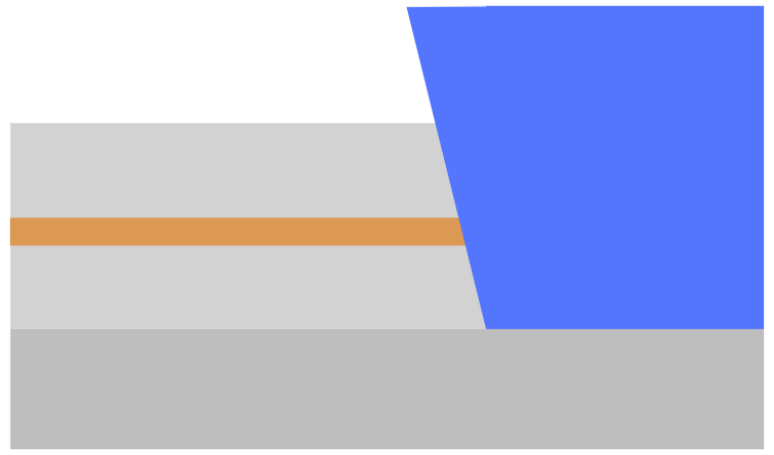
No cleaning performed

M. Hatefipour et al. arXiv:2108.08899 (2021)

Summary

- Fabrication of gate controlled InAs/NbTiN Hall-bar
- Negative resistance observation at 2DEG/Superconductor interface in IQHS
- Lower band value of AR at 2DEG/Superconductor by ~15%



Speaker, Reference	Onder Gul, arXiv:2009.07836, arXiv:1609.08104	Gleb Finkelstein, arXiv:1907.01722	Javad Shabani, arXiv:2108.08899
Top-down			
Cross-section			
Materials	Graphene, NbTiN	Graphene, MoRe	InAs 2DEG, NbTiN
Main observations (R is nonlocal voltage divided by drain current)	$R \approx \mathrm{const} < 0$ for integer and fractional QHE; $R \to 0$ at $W \gtrsim 0.2\mu m$	Oscillatory R, $\langle G \rangle = 0$; $\mathrm{var}(R) \to 0$ with $T \gtrsim 0.2K$; sudden jumps in $R(B)$	$R \approx \mathrm{const} < 0$ in integer QHE plateaus; $R < 0$ persists to $I \gtrsim 5\mu A$