Local probing of Quantum Spin Hall edge states

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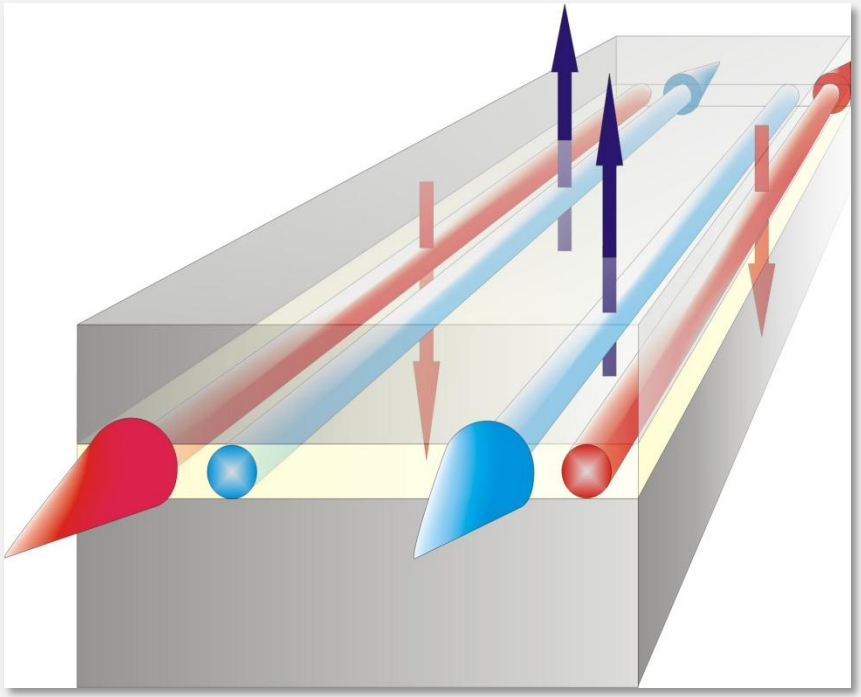
The Quantum Spin Hall Effect

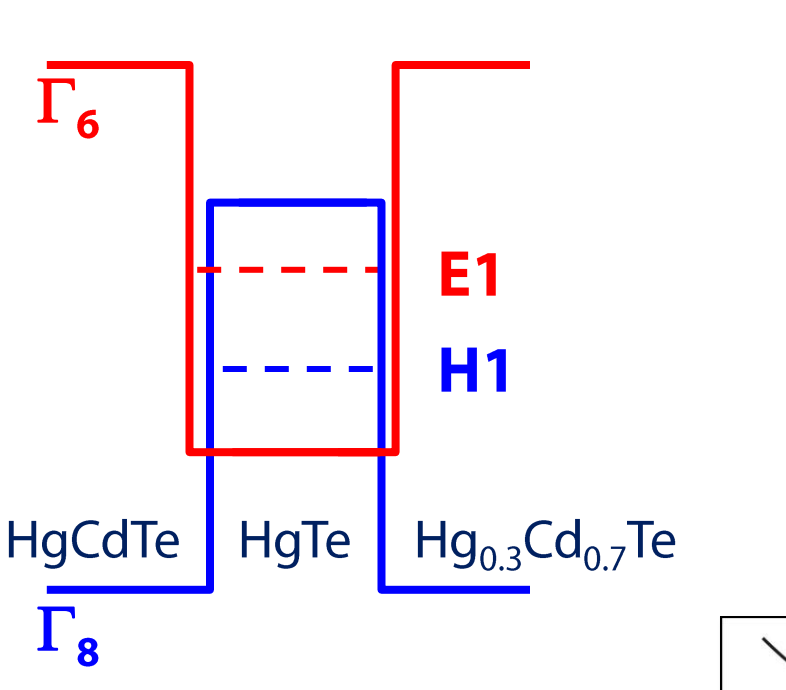


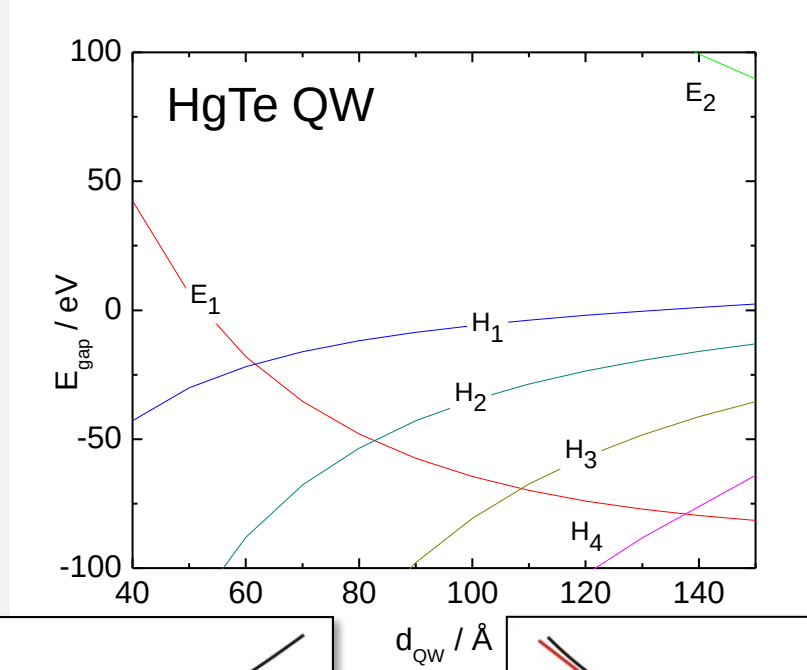
Quantum Spin Hall state is 2D manifestation of a topological insulator

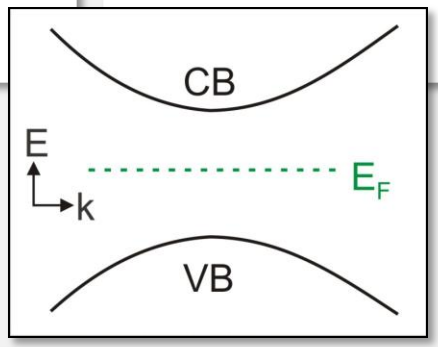
- spin-polarized edge states
- backscattering suppressed by time-reversal symmetry
- dissipationless transport along sample edge

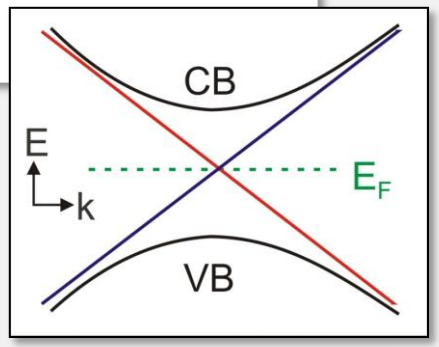
C.L. Kane and E.J. Mele, PRL **95**, 226801 (2005)
B.A. Bernevig and S.C. Zhang, PRL **96**, 106802 (2006)

HgTe quantum wells



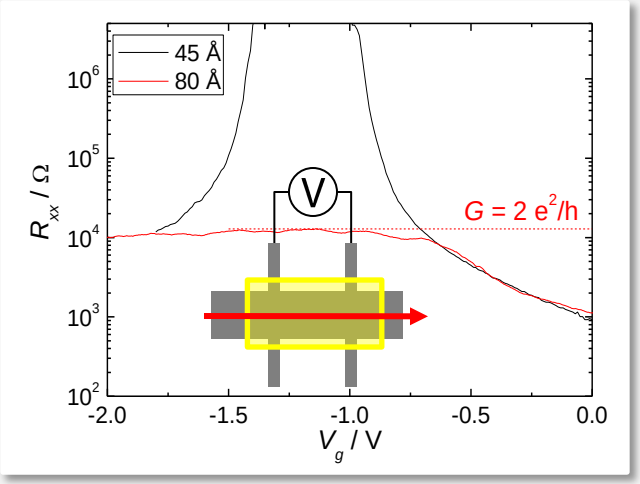




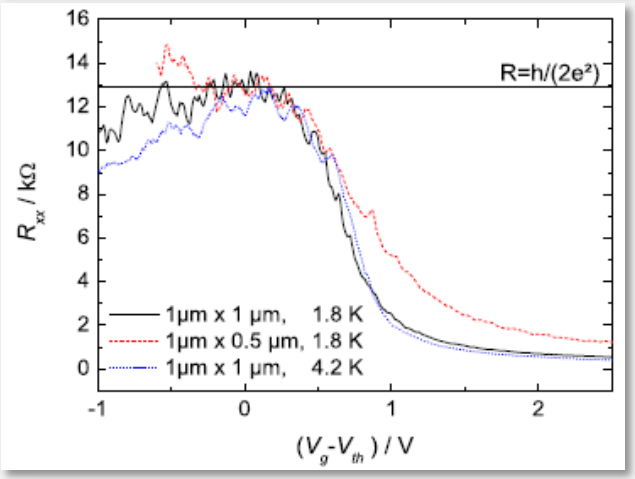


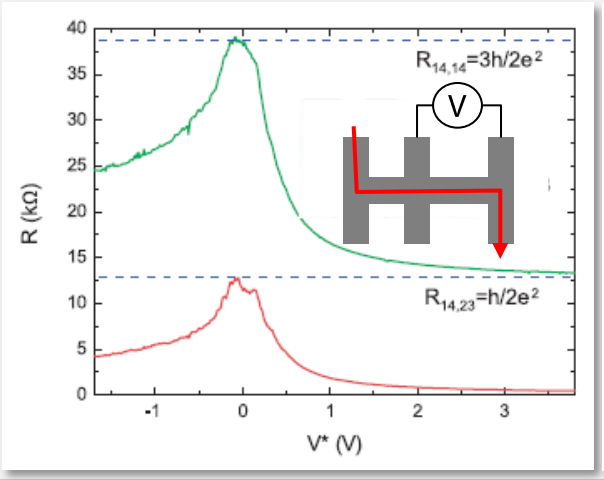
B.A. Bernevig, T. L. Hughes, and S. C. Zhang, Science **314**, 1757 (2006)

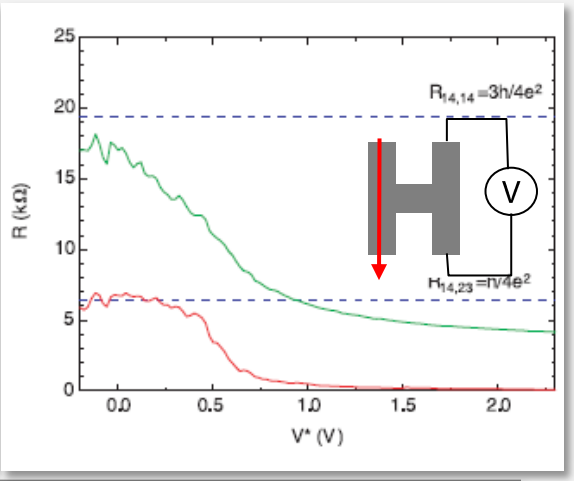
Experimental observations



- QSHE observed for d_{QW} > 63 Å, thinner QWs show insulating behavior
- G = $2e^2/h$ not depending on aspect ratio
- non-local measurements
  → edge state transport



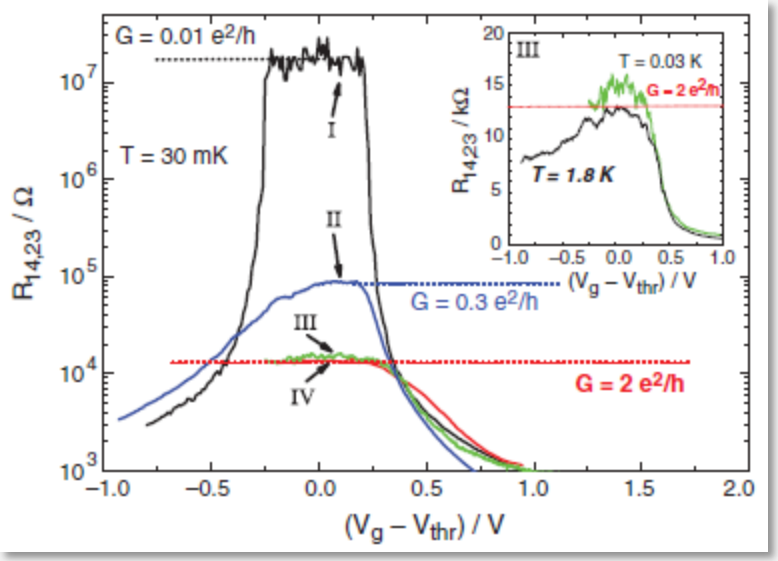


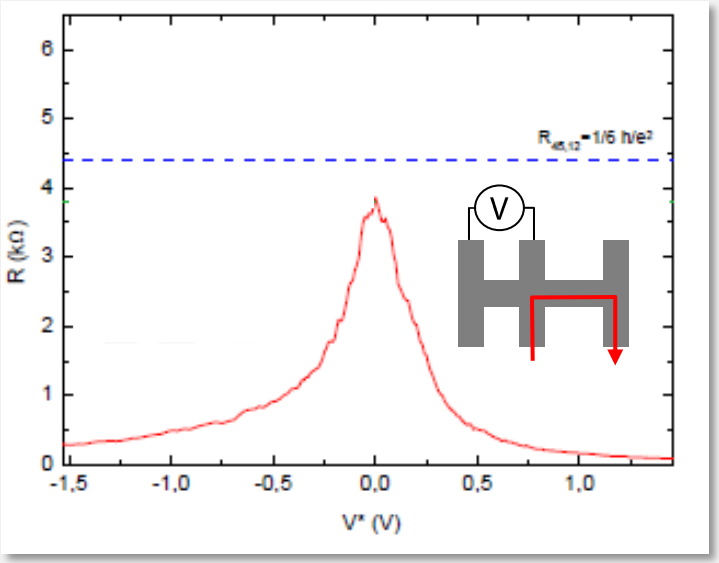


M. König *et al.*, Science **318**, 766 (2007); M. König *et al.*, JPSJ 77, 031007 (2008); A. Roth *et al.*, Science **325**, 294 (2009)

Scattering of QSH edge channels

- mean free path ~ 1 µm
- single impurity sufficient for full equilibration





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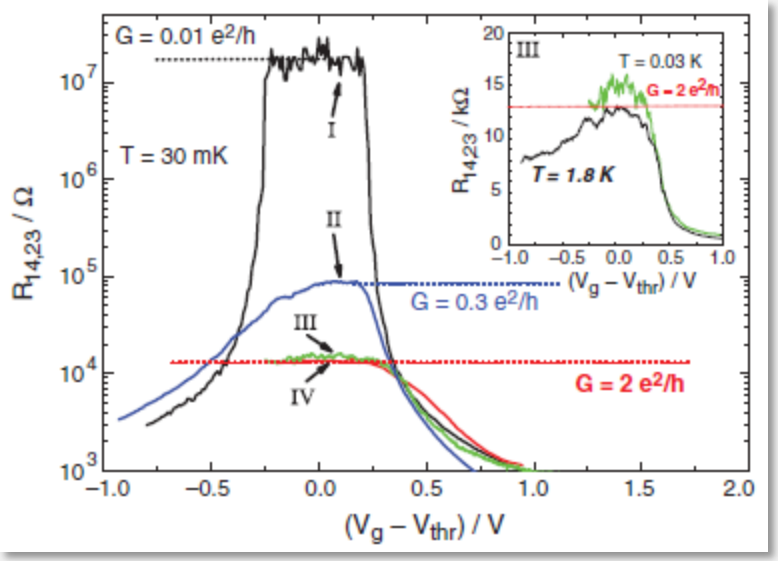
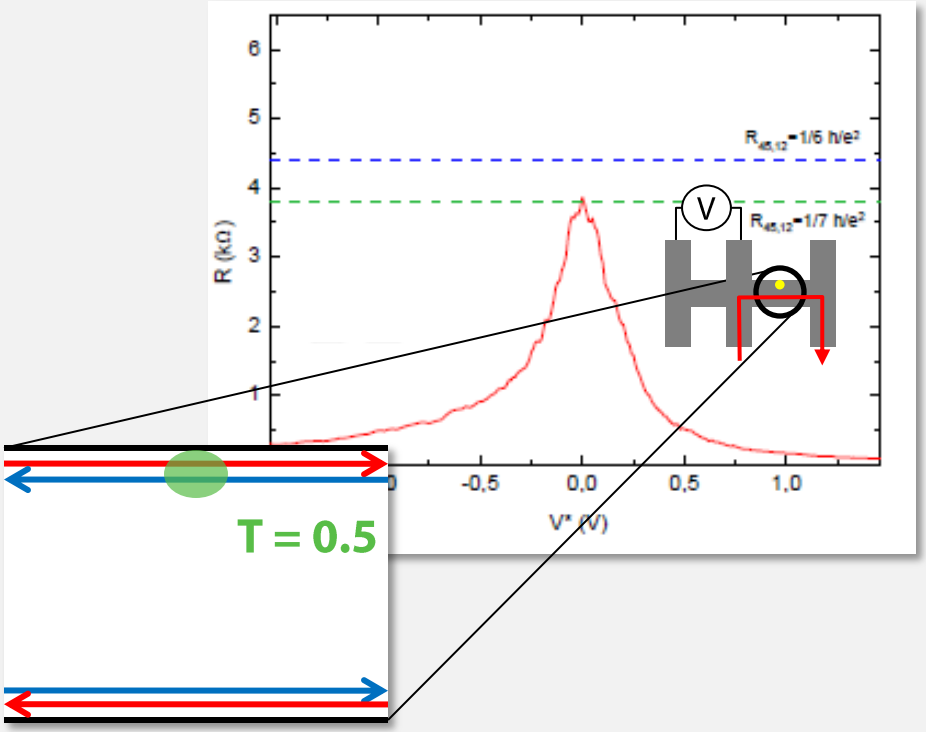
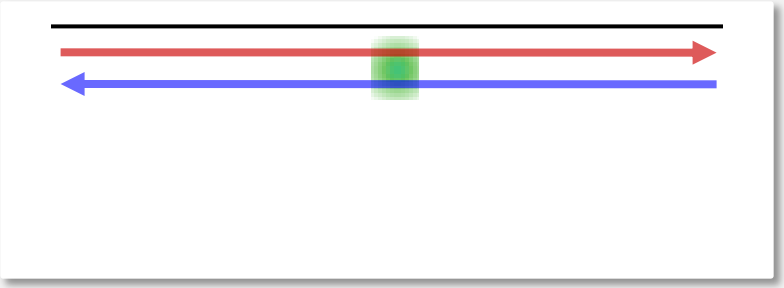
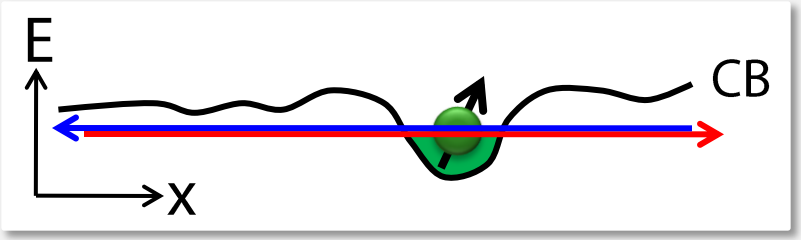


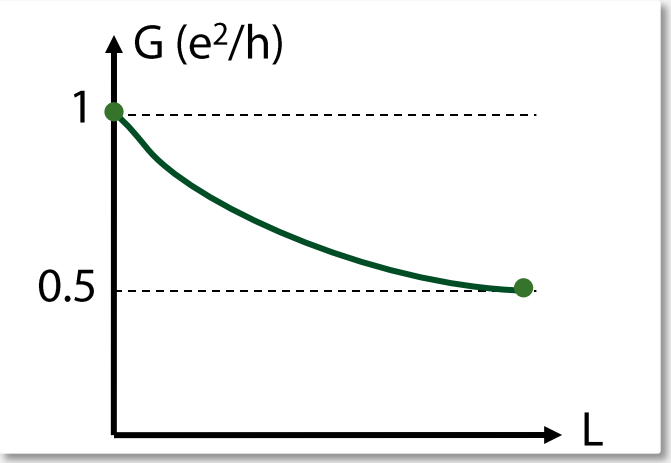


Scattering mechanisms

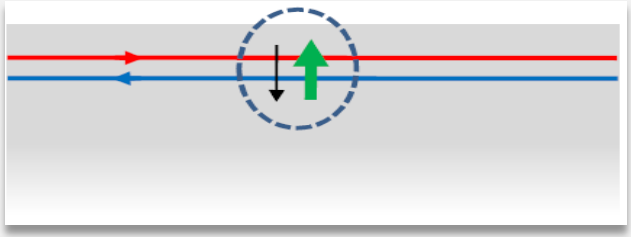
- quasi-2D region at sample edge

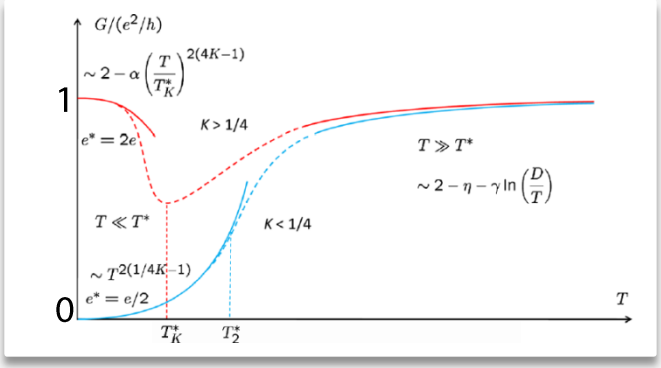






- magnetic impurities

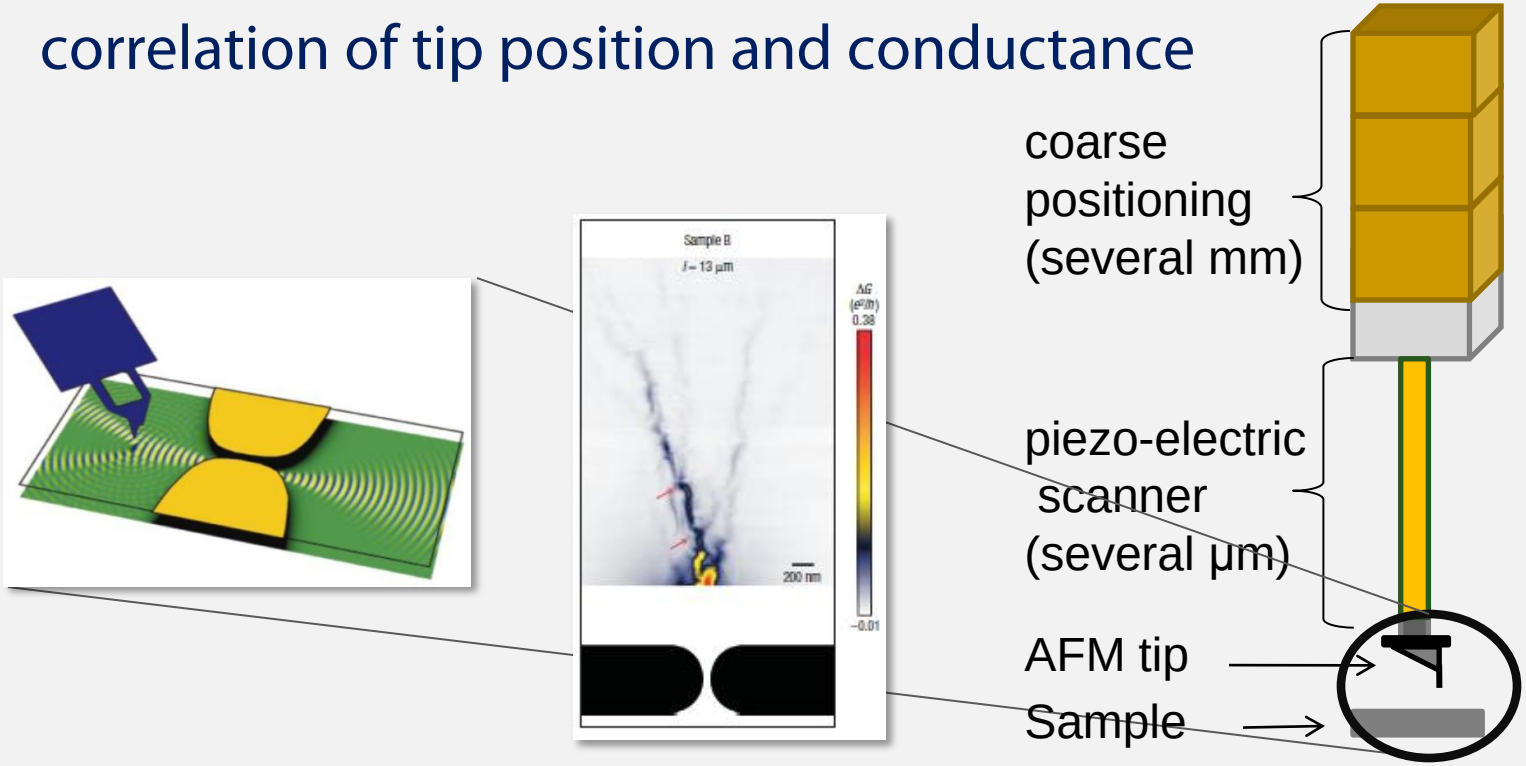




A. Roth *et al.*, Science **325**, 294 (2009); J. Maciejko *et al.*, PRL **102**, 256803 (2009)

Scanning Gate Microscopy

- effect of a local potential modulation on transport properties
- charged AFM tip is scanned over surface
- correlation of tip position and conductance



M. Topinka *et al.*, Nature **410**, 183 (2001); M. Jura *et al.*, Nat. Phys **3**, 841 (2007)

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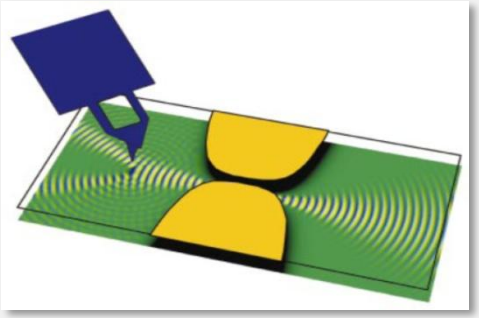
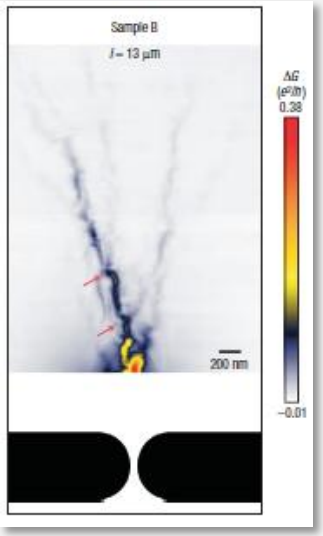
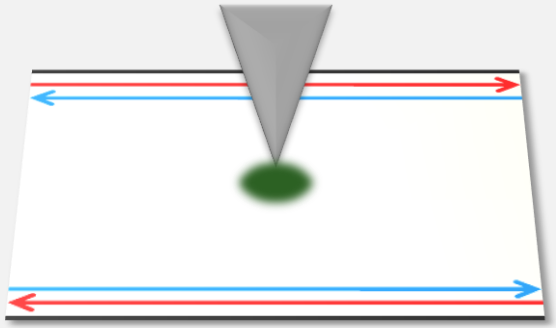
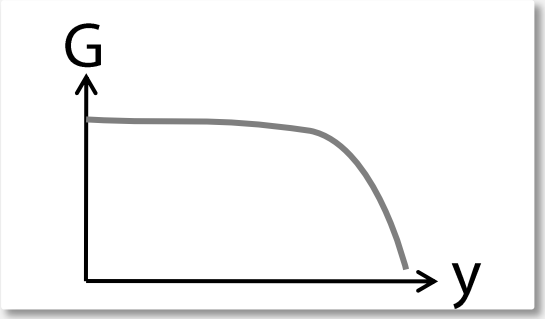


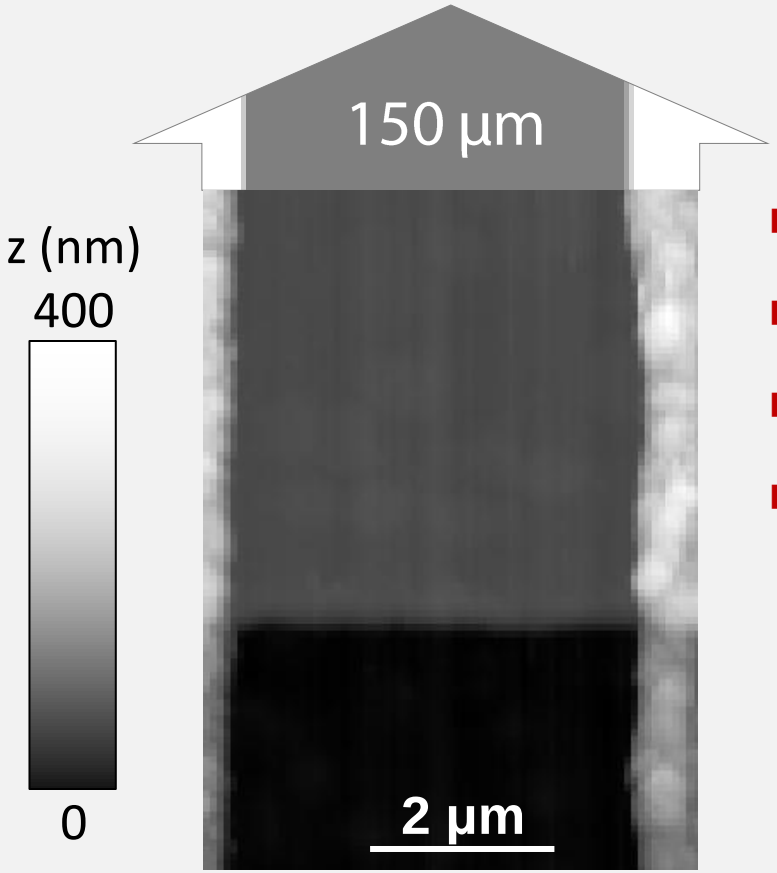






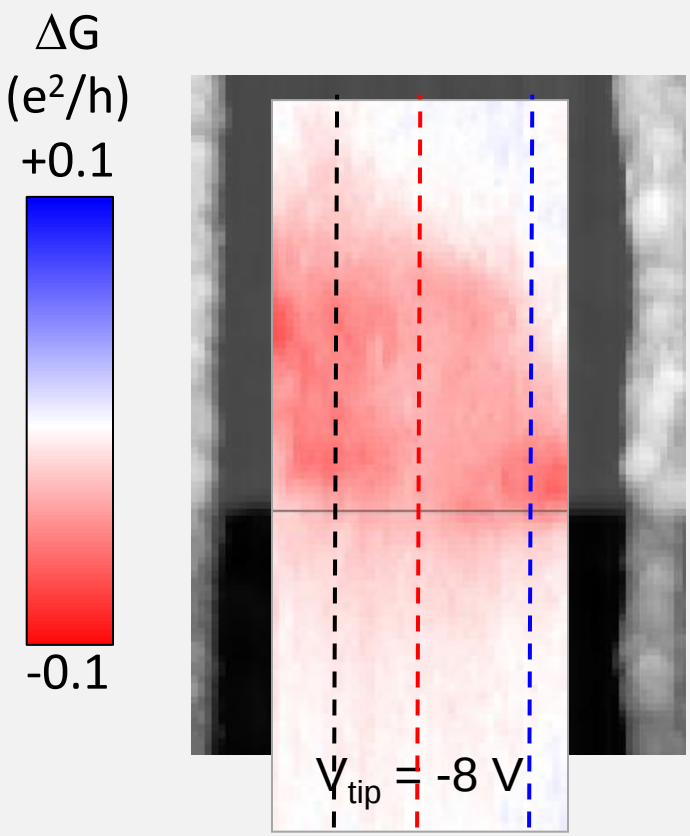
M. Topinka *et al.*, Nature **410**, 183 (2001); M. Jura *et al.*, Nat. Phys **3**, 841 (2007)

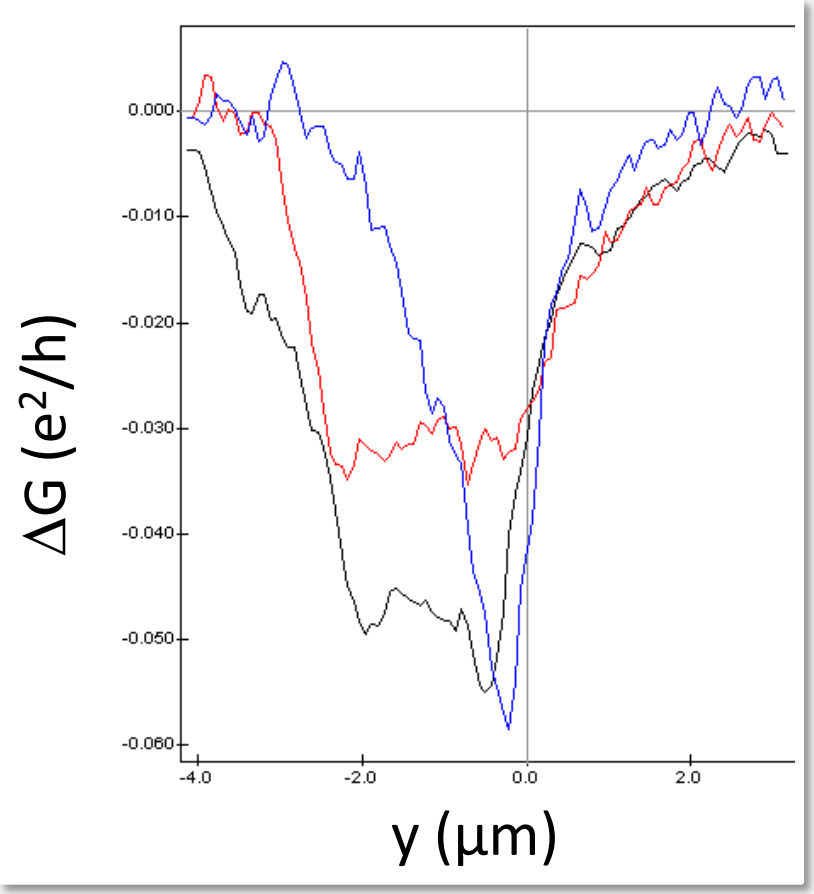
Device characterization



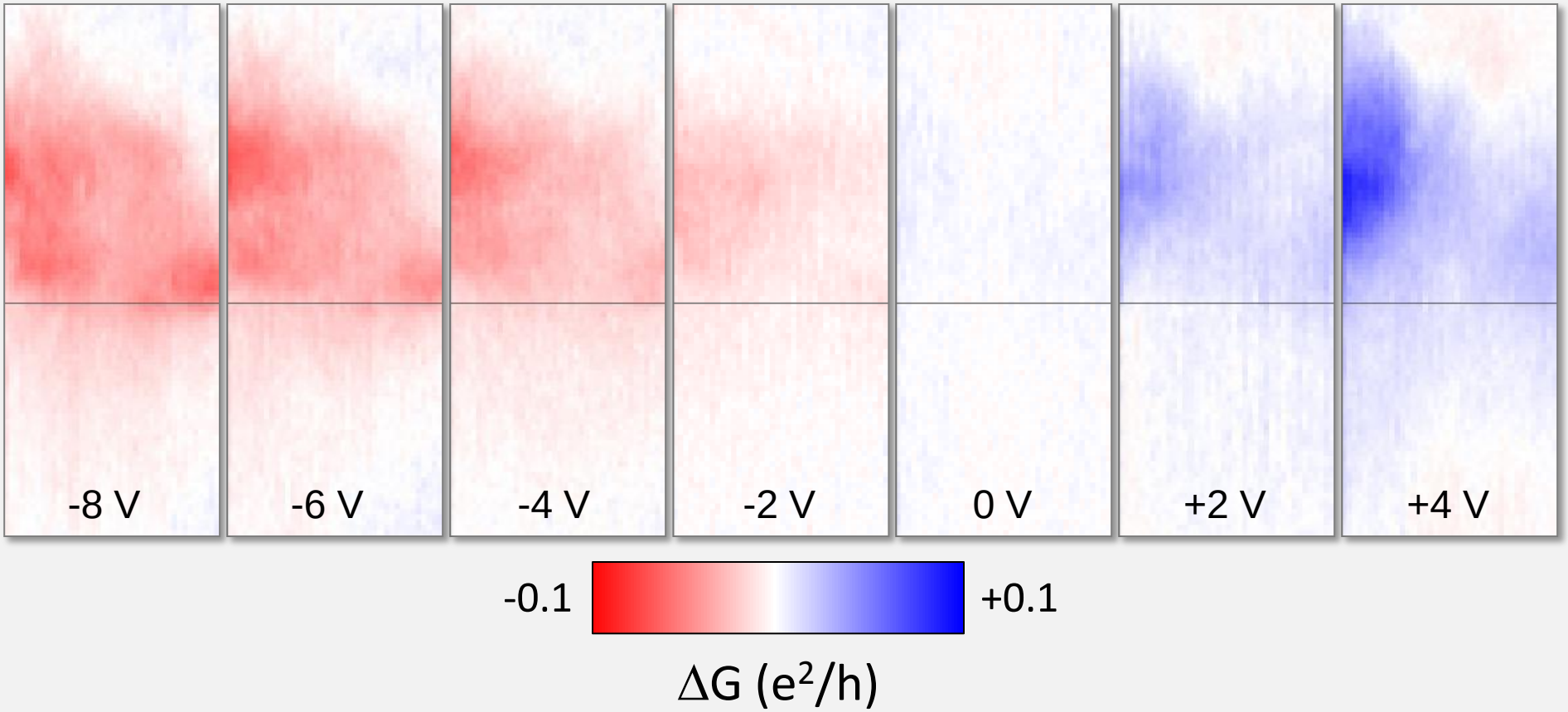
- HgTe quantum well
- $d_{QW} = 7.0$ nm $\Rightarrow E_{gap} \approx 20$ meV
- sample intrinsically undoped
- $G \approx 3\ e^2/h$
  → contribution from p-type bulk

Scanning Gate measurements

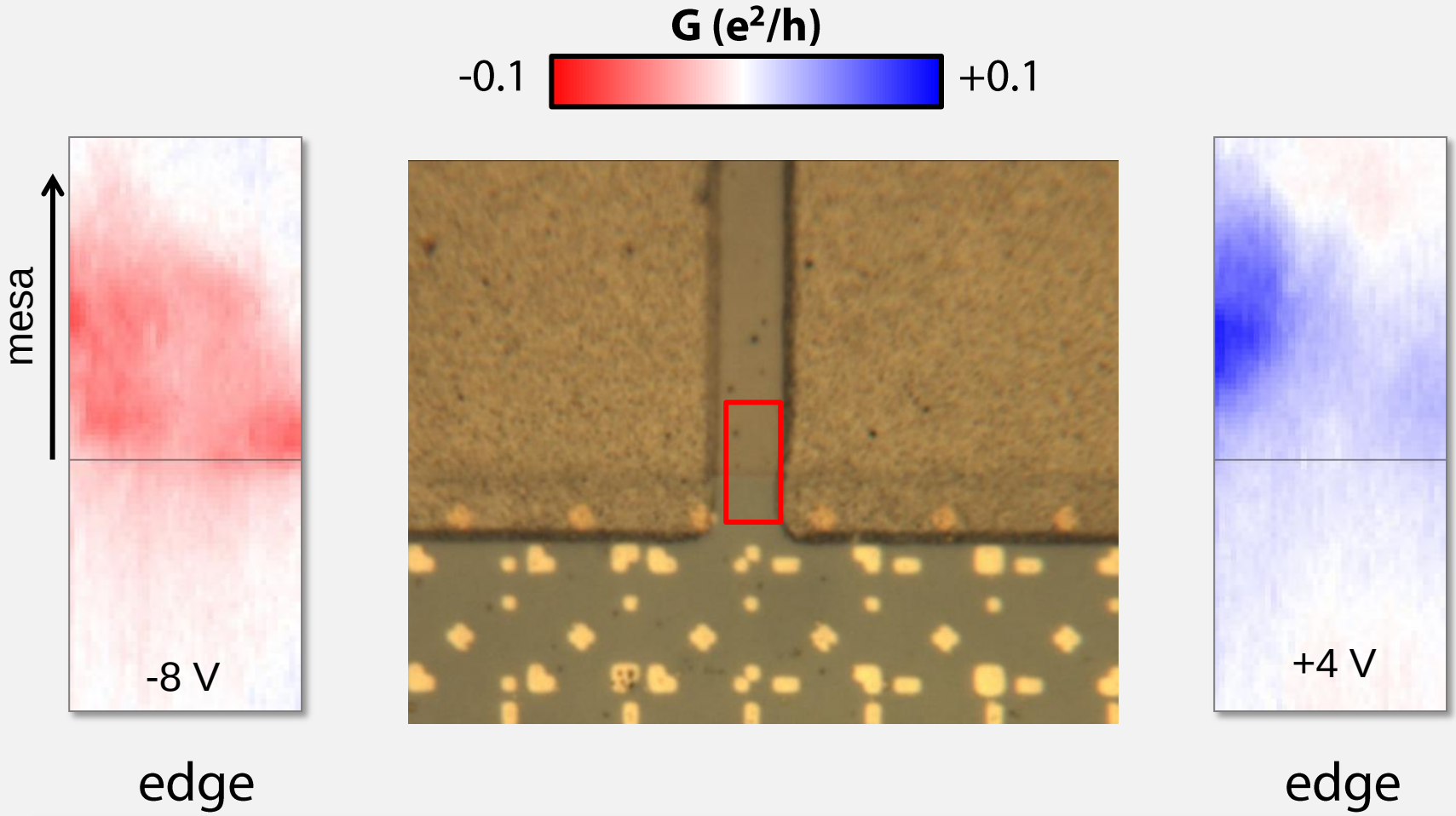




Scanning Gate measurements



Edge vs. bulk



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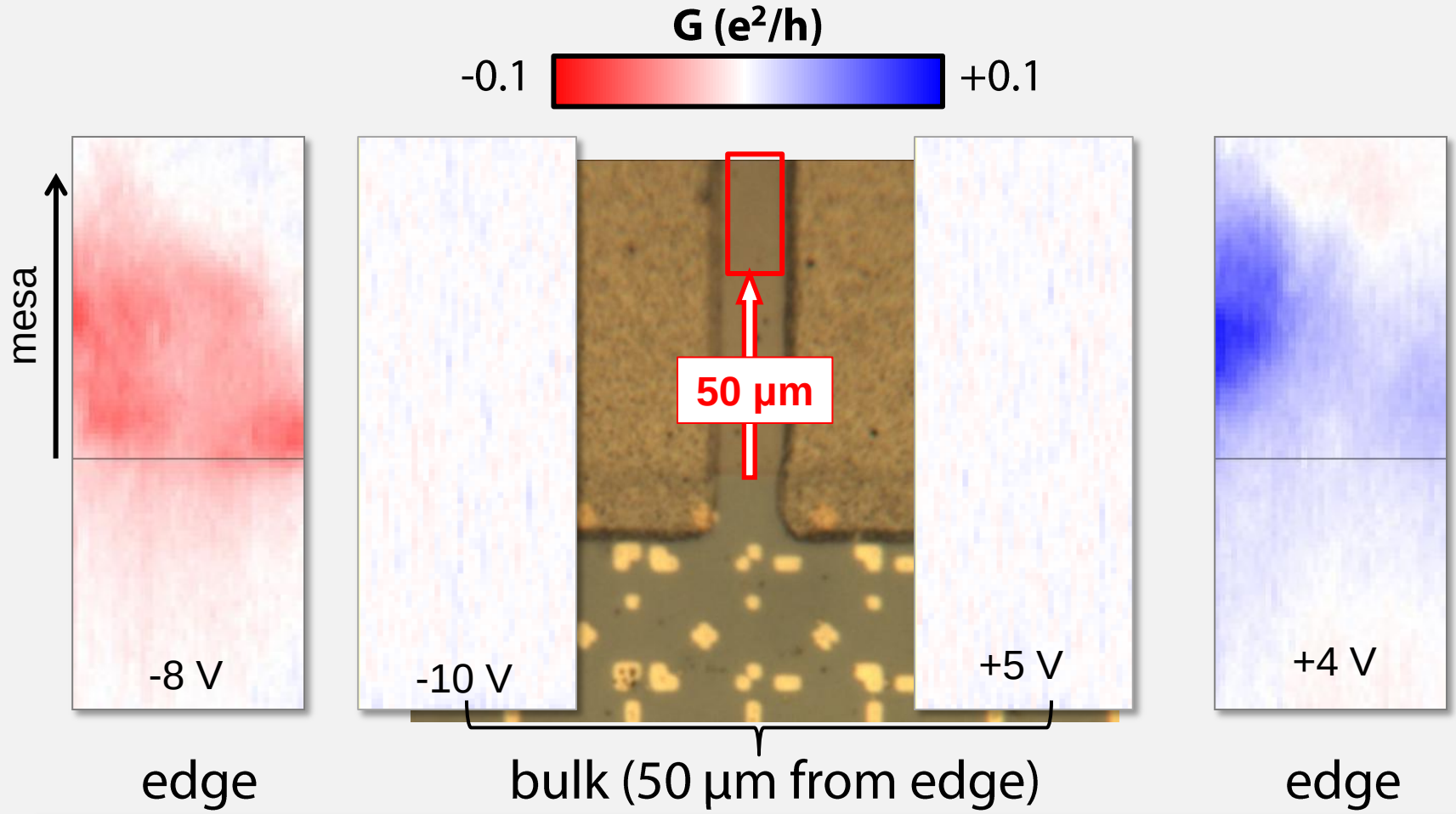

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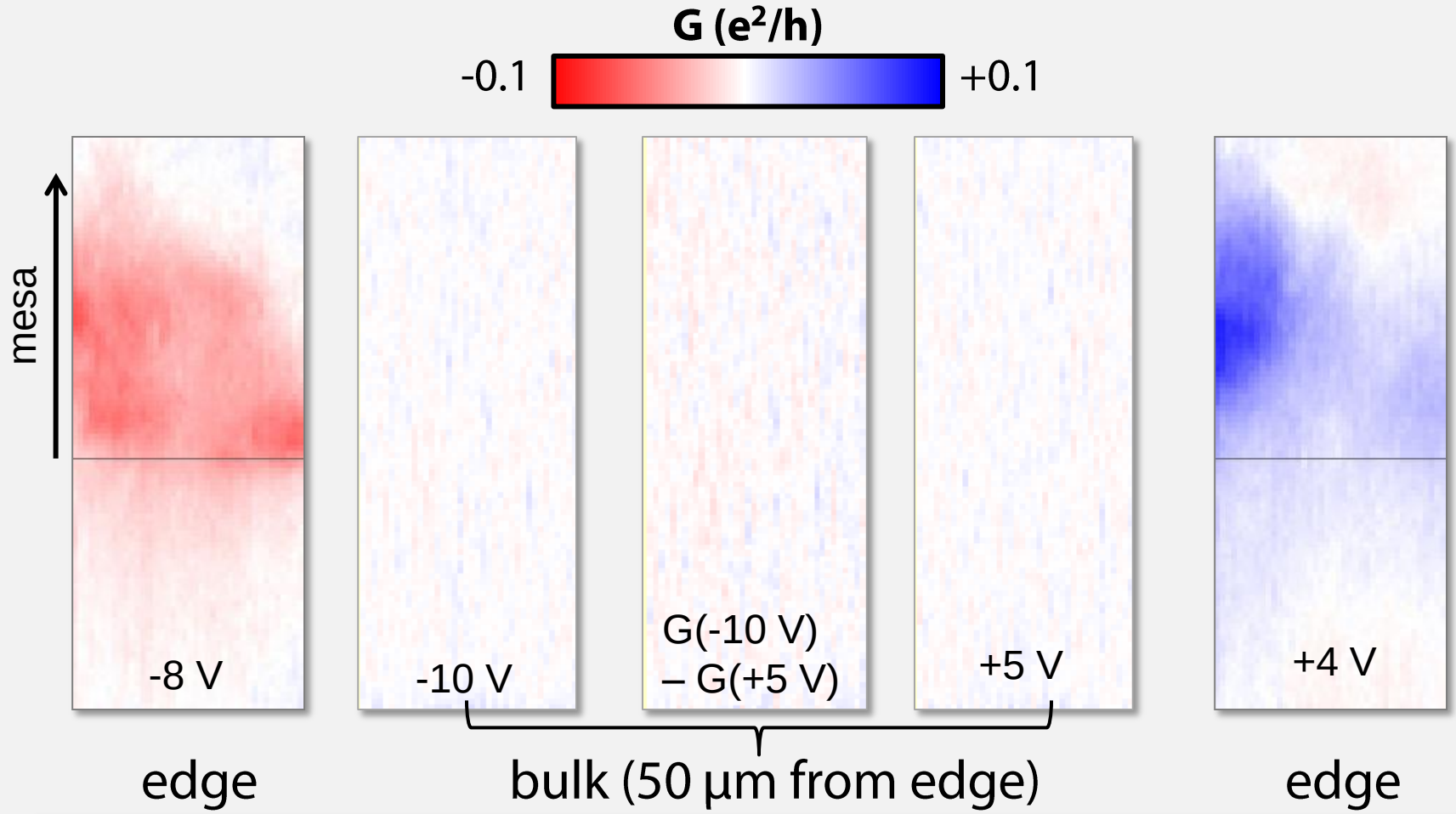
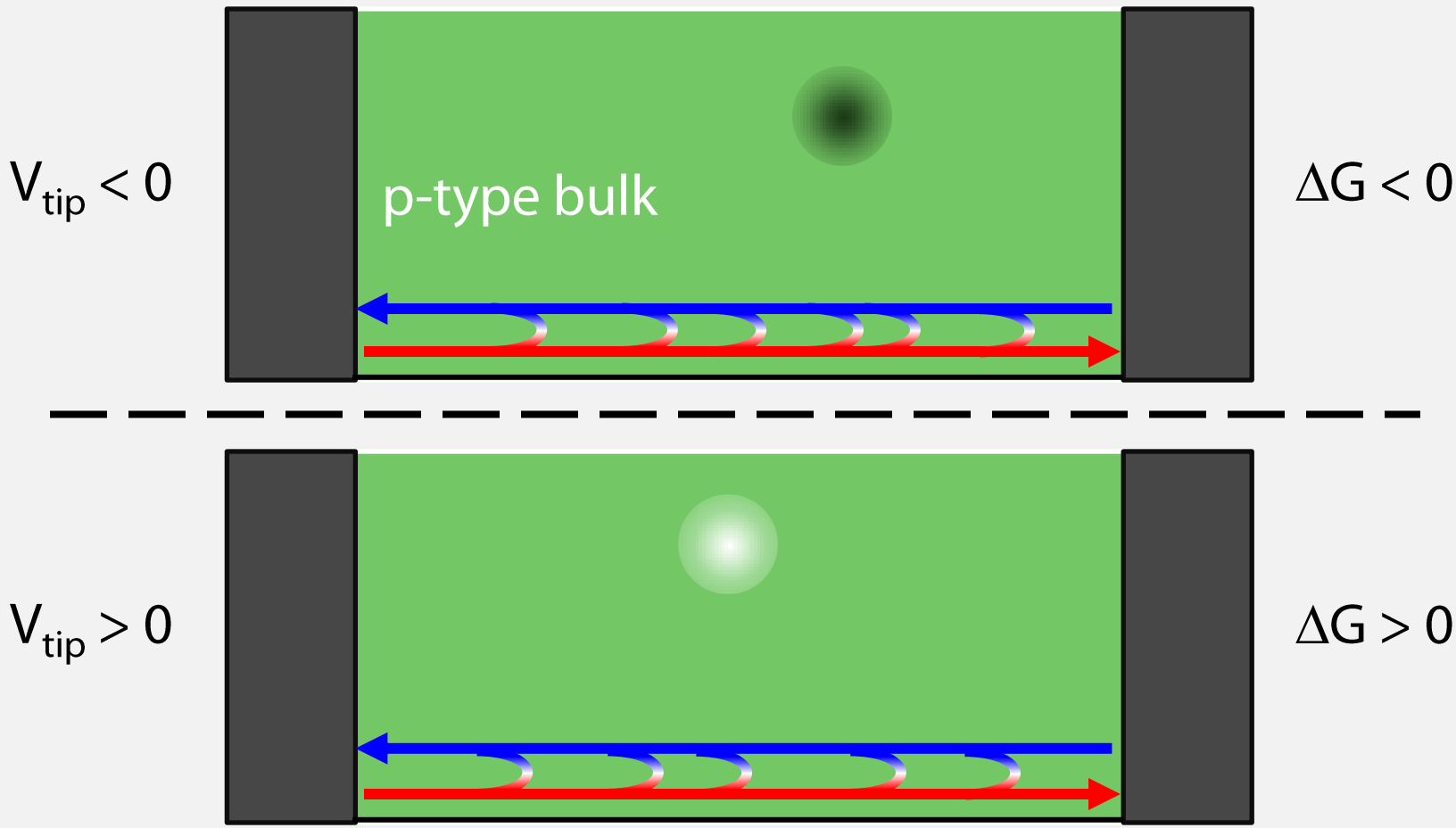
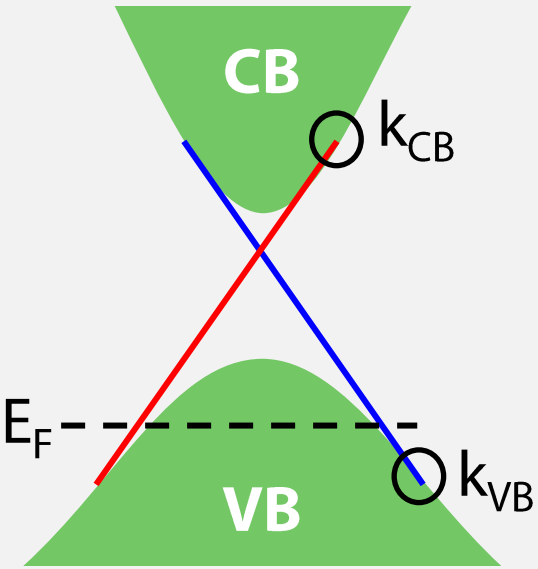

G (e²/h)
-0.1
+0.1
mesa
-8 V
-10 V
G(-10 V)
– G(+5 V)
+5 V
+4 V
edge
bulk (50 µm from edge)
edge

A cartoon model



Width of the edge states



- edge states have a finite width
- exact value depends on position of E_F
- L ~ 1 μm reasonable for our sample with low density of p-type carriers in the bulk

$$L^{-1} = N - \sqrt{N^2 + (k - k_{VB})(k - k_{CB})}$$

N. Wada *et al.*, arXiv:1005.3912

Summary and future directions

- Scanning Gate measurements on HgTe devices
- Clear gate effect near mesa edge, possibly related to QSH edge states

- Control of bulk carriers
- Stronger localization of tip effect

- spatial mapping of edge states
- sensitivity to potential fluctuations
- dominant scattering mechanism?

Acknowledgements

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