

Edge conduction in monolayer WTe_2

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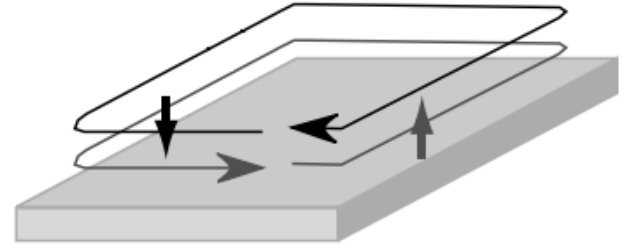
Yemliha Bilal Kalyoncu

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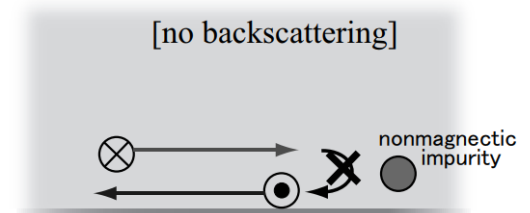
2D Topological Insulators

2D topological insulator \Rightarrow Helical 1D edge mode



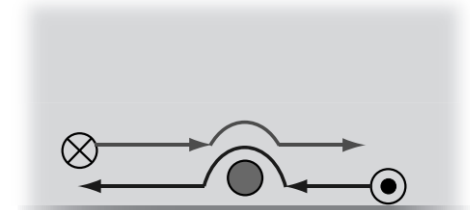
Quantum wells of Hg/CdTe and InAs/GaSb

Edge conductance not quantized
mesoscopic fluctuations as a function of gate voltage

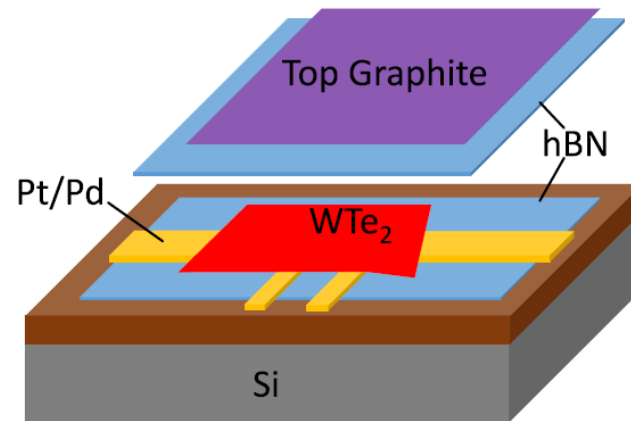
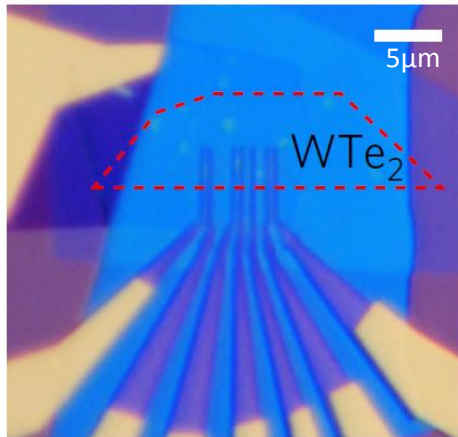
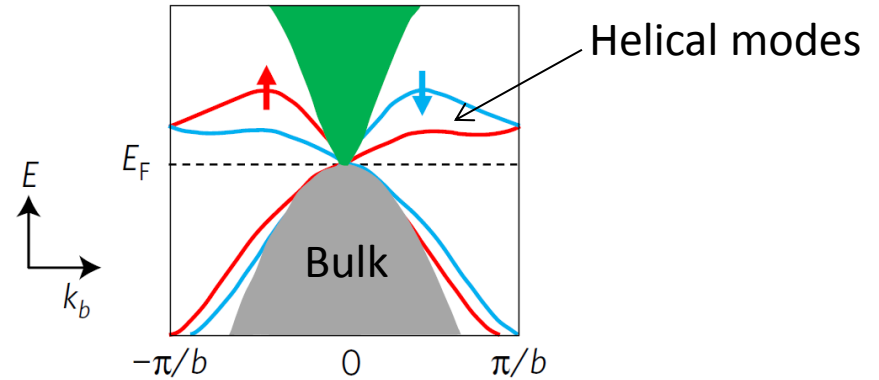
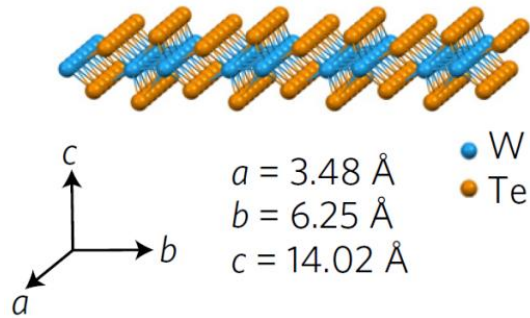


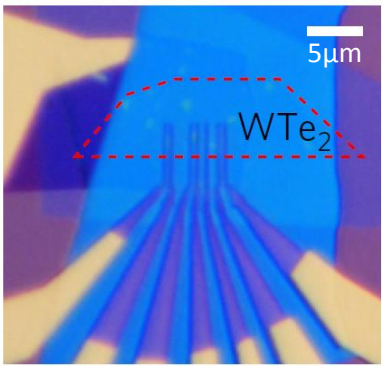
Existence/Absence of elastic backscattering ?

Conductance at high magnetic field



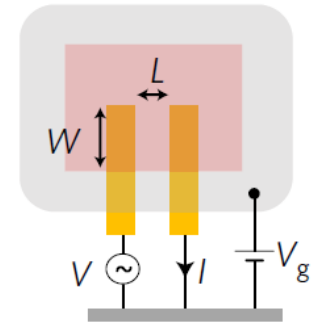
Tungsten Ditelluride WTe_2



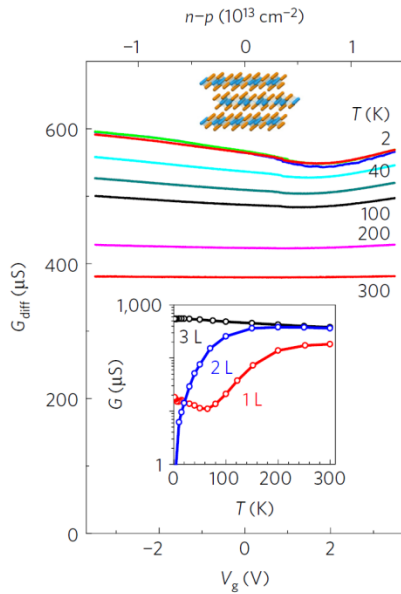


WTe₂

100 μ V a.c. Excitation
 3 mV d.c. bias
 Effects only 1.6K, suppresses ZBA

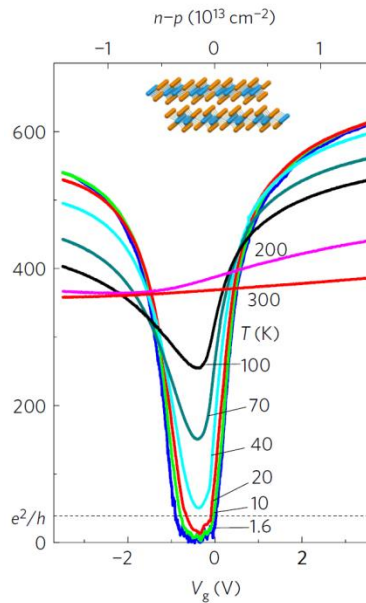


3Layer



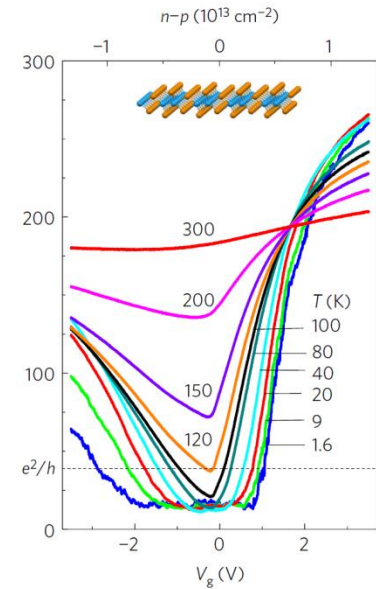
Stays metallic

2Layer



Sharp dip at around $V_G=0$
 Stays metallic for $V_G \gg 1$

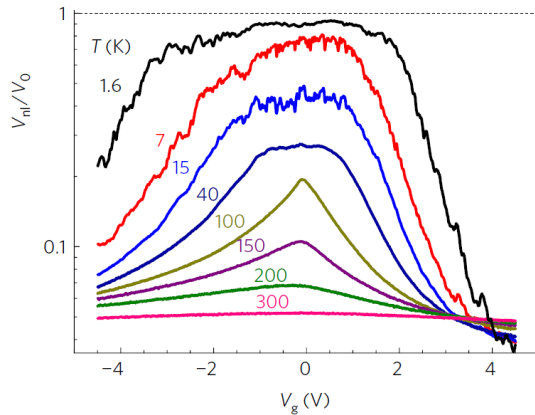
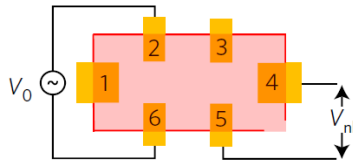
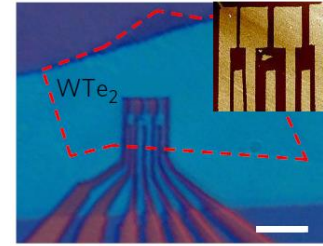
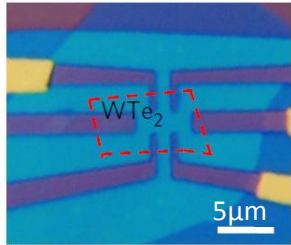
1 Layer



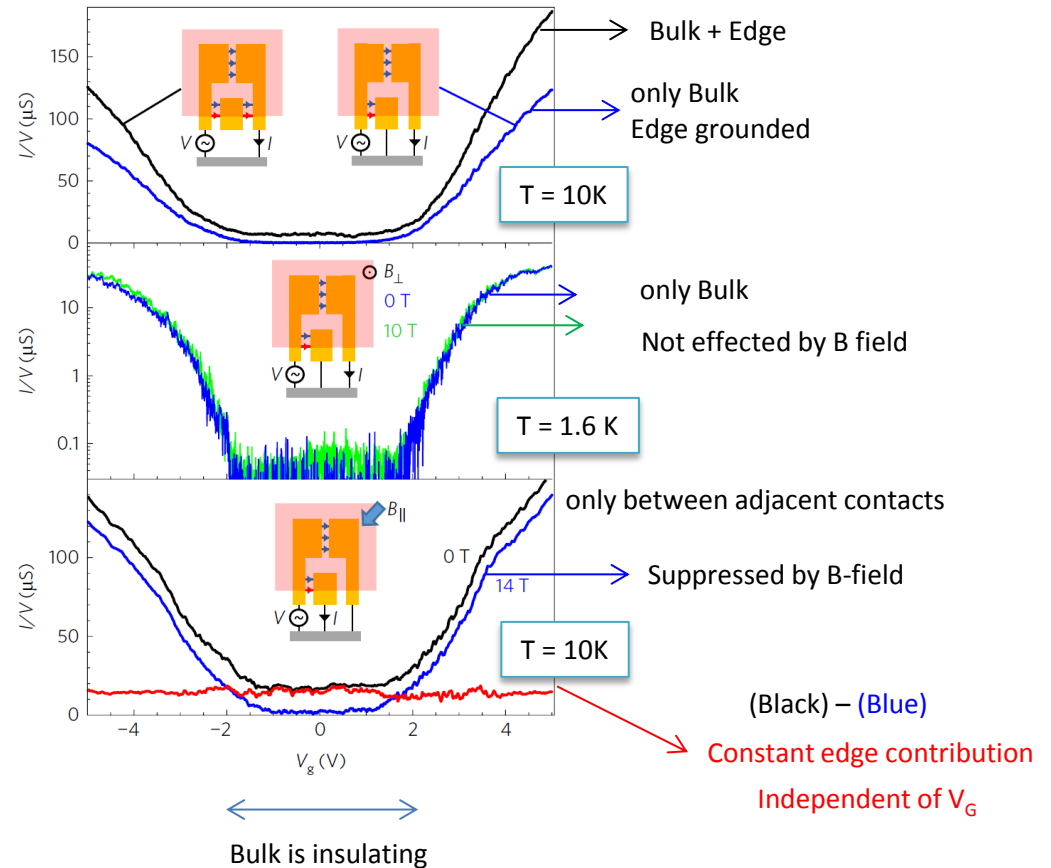
Wider minimum
 $100 > T$ plateau of conductance

$100 > T \rightarrow$ Bulk is insulating
 \Rightarrow Edge conduction

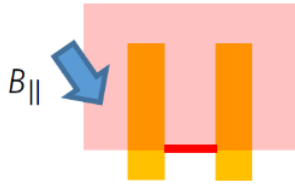
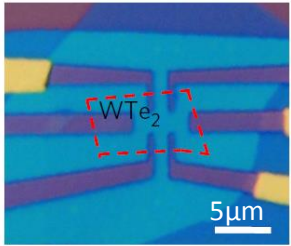
Edge Conduction



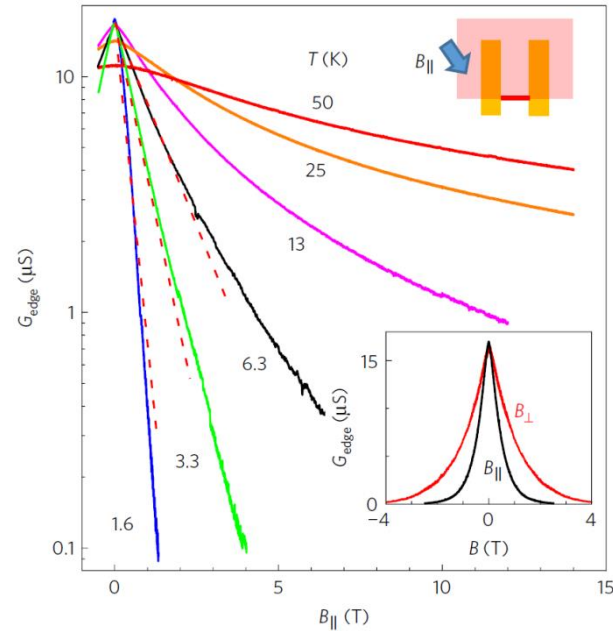
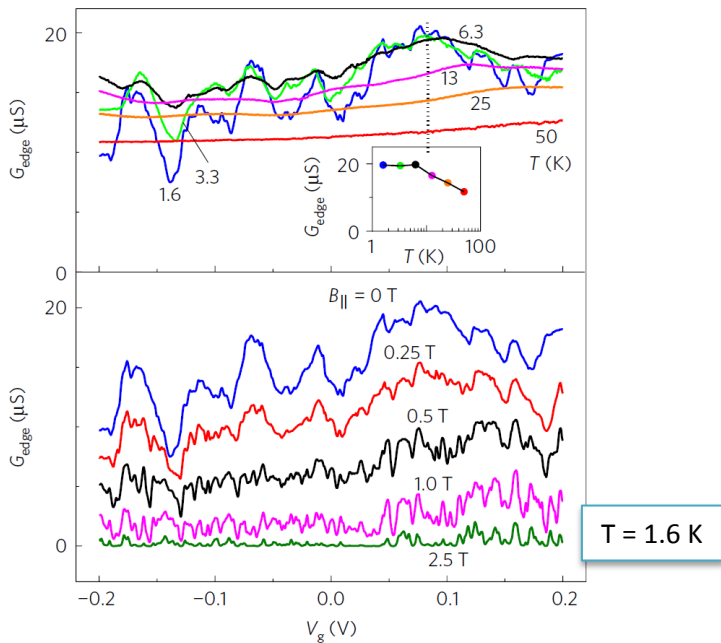
$$\frac{V_{nl}}{V_0} \approx 1 \rightarrow \text{Edge Conduction}$$



Edge Conduction



Negligible bulk contribution



$$G_{edge} = G_0 e^{-\alpha B_{||}/T}$$

$$\Delta_B = g \mu_B B_{||}$$

$$G_0 = 17 \mu S$$

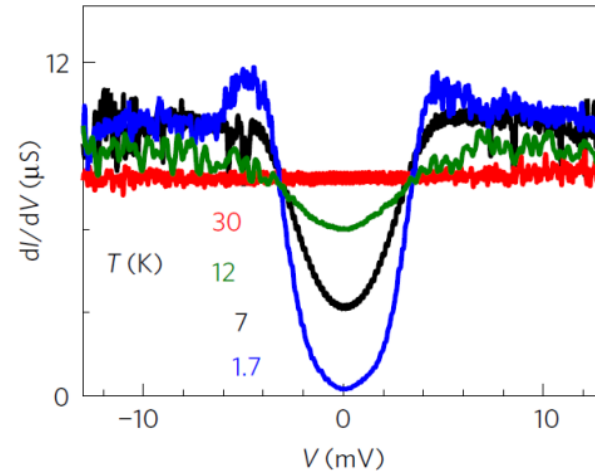
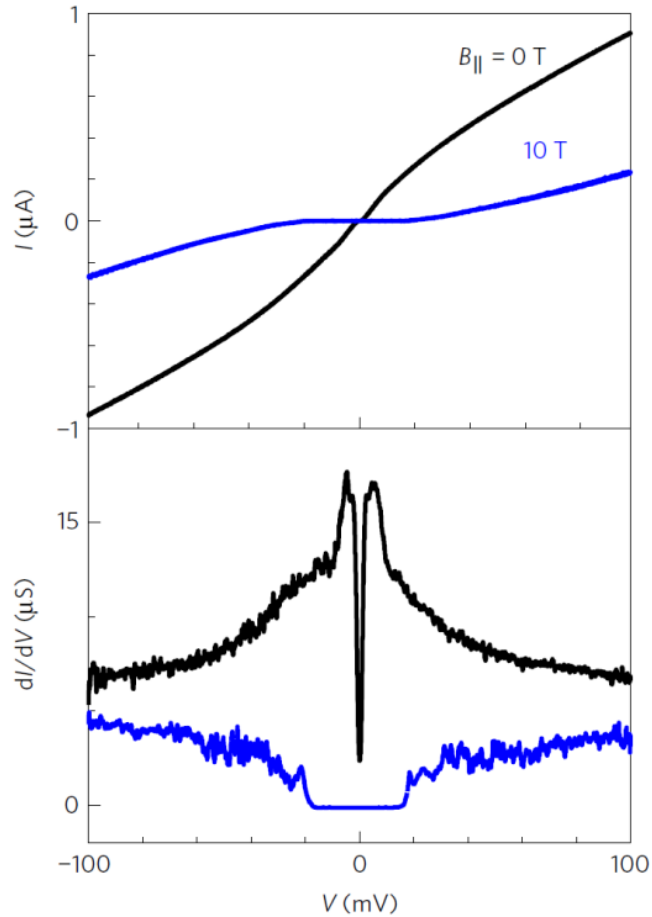
$$\alpha = 5$$

$$g = \alpha k_B / \mu_B \approx 7.5$$

Possibility of Edge Conductance

- G_{edge} is independent of gate voltage
- No Edge conduction in bilayer
- $B_{||}$ suppresses G_{edge} \Leftarrow TR symmetry is broken

Zero Bias Anomaly

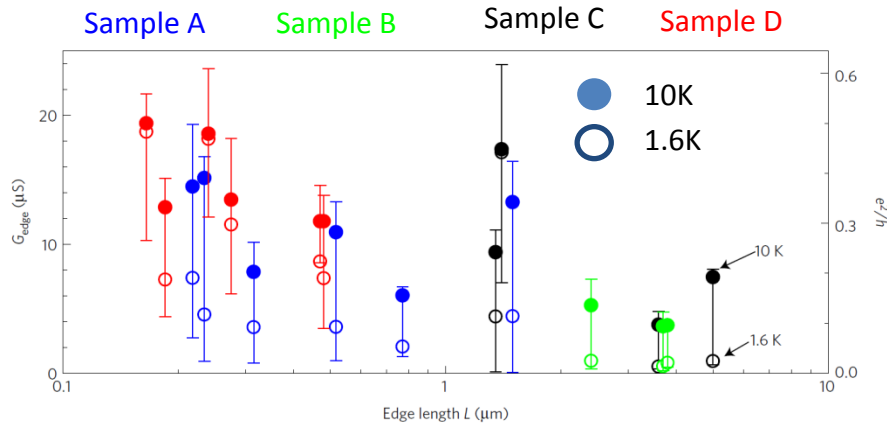


All edges show dip at 1.6K

ZBA \leftrightarrow mesoscopic fluctuation

B field \Rightarrow suppresses ZBA and mesoscopic fluctuations

Value of G_{edge}



4 samples
19 adjacent contact pairs

Expected $G_{\text{edge}} = 1 e^2/h = 38.7 \mu\text{S}$

Possible reasons:

- Imperfect transmission between edge and the metal contacts.
- Backscattering from multiple magnetic impurities*
- Puddles in disorder potential*

If some form of backscattering is allowed in a quantum wire,
ZBA can develop due to interaction effects*

We do not observe the quantized conductance that would be a definitive signature of a 2DTI

Discussion

Suppose single helical edge in disorder potential

If backscattering, stronger at weak points

$$B_{\parallel} = 0 \Rightarrow \frac{1}{2} e^2/h$$

\Rightarrow Rapid mesoscopic fluctuations

If the reason is quantum interference, no B_{\perp} dependence

As T lower \Rightarrow stronger scattering \Rightarrow ZBA

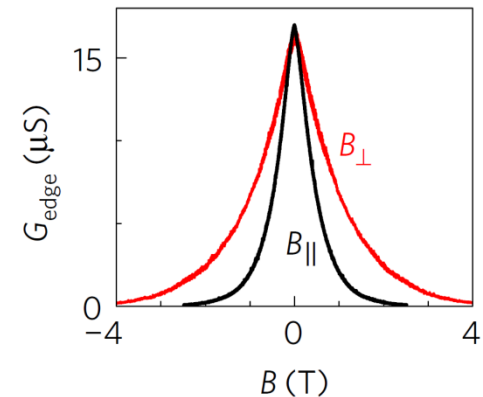
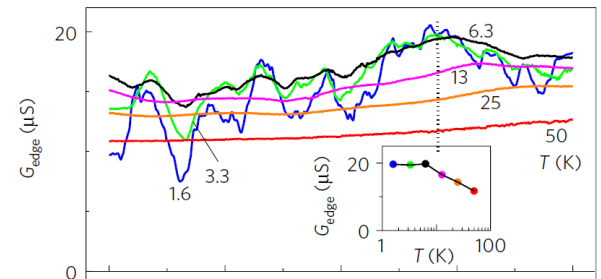
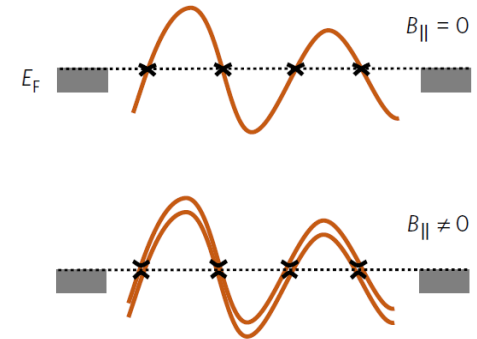
Long edges \Rightarrow smaller conductance

As T higher \Rightarrow coherence length decreases

$\Rightarrow G_{\text{edge}}$ decrease (above 6K)

Magnetic field opens gap Δ_B

$\Rightarrow G_{\text{edge}}$ has factor $e^{-\Delta_B/k_B T}$



Conclusions

Monolayer WTe₂ is a possible 2D Topological Insulator

Nonlocal measurements / Pincer shaped contacts to show edge conductance

Dependence of G_{edge} on B_{\parallel} , B_{\perp} and T

Zero Bias Anomaly

$$G_{\text{Edge}} < 1 e^2/h = 38,7 \mu\text{S}$$

Discussion on the scenario of a single helical edge mode

Outlook

- Excitonic insulator : electron-hole correlations below 100K
- Edge of exfoliated monolayer: orientation, roughness, chemical details
- Band structure tuning: chemical substitution, strain

Thank you

In studying the edges in the main text (Figure 3 and 4), we focused on two-terminal measurements. Four-terminal measurements were not presented because they yield the same results, implying the contacts to the edge were “perfect” in the sense that the current can only pass between adjacent edges via the metal of the contact in between. To illustrate this, Fig. S4a shows the parallel field dependence of the conductance at $V_g = 0$ in device MW2, in which the black and red curves were measured with two- and four-terminal configurations respectively as defined in the inset ($G_{23} = I_{23}/V_{23}$, $G_{14,23} = I_{14}/V_{23}$). Even as the magnetic field suppresses the edge conductance, both two and four-terminal measurements give almost identical conductance values.

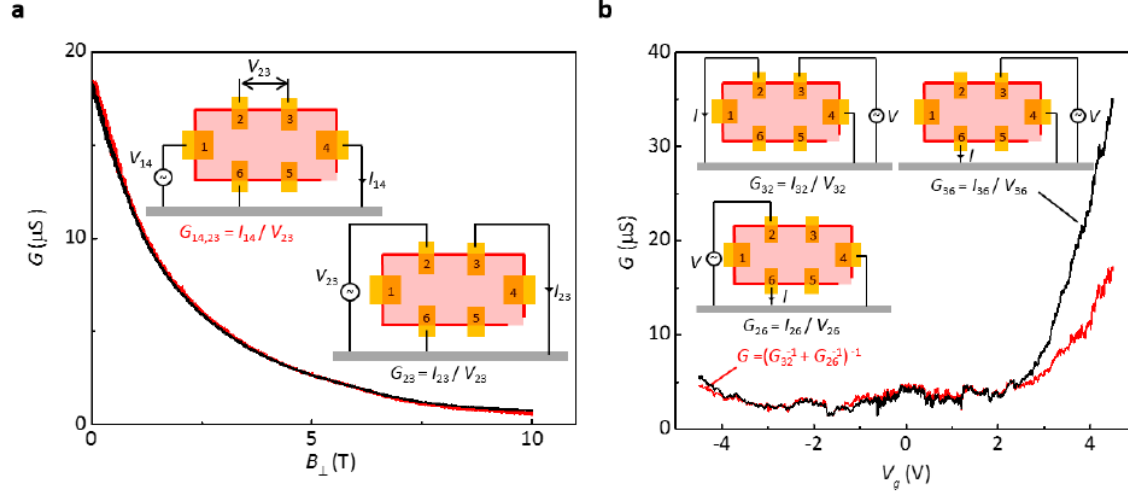


Figure S4 | Comparison of two-terminal and multi-terminal measurements in device MW2. a, Perpendicular magnetic field dependence of the conductance of a particular edge at 6.5 K, $V_g = 0$; black and red curves are two- and four-terminal measurements respectively as labeled, with 2 and 3 the voltage contacts in both cases. **b,** Gate dependence of direct two-terminal conductance G_{36} (black) and series conductance $(G_{32}^{-1} + G_{26}^{-1})^{-1}$ (red), at 1.6 K and $B = 0$.

Figure S4b compares the gate dependence of G_{36} with $(G_{32}^{-1} + G_{26}^{-1})^{-1}$ in device MW2 with contact 4 grounded, here G_{36} , G_{32} , G_{26} are two-terminal conductances. On the plateau region, there is minimal difference between the two, even for the mesoscopic fluctuations. This implies a strong contact coupling and, again, that the conductance is determined entirely by the edge in this regime, since bulk current flow would violate this equivalence.

SI-4. Length dependence of the monolayer 2D bulk conduction

Above 100 K, two-terminal conduction is dominated by the 2D bulk. Fig. S5 shows the two-terminal resistance as a function of aspect ratio L/W for device MW1 at $V_g = 0$. If the edge contribution is small, the two-terminal resistance is given roughly by $R = \rho_s \frac{L}{W} + 2 R_c$. From the linear fit (for large aspect ratio a deviation from the linear fit is expected due to current spreading) we extract the sheet resistivity ρ_s , which increases from 20 k Ω at room temperature to 125 k Ω at 155 K, consistent with the insulating behavior for zero gate voltage. The extracted contact resistance R_c is approximately 2 k Ω per contact.

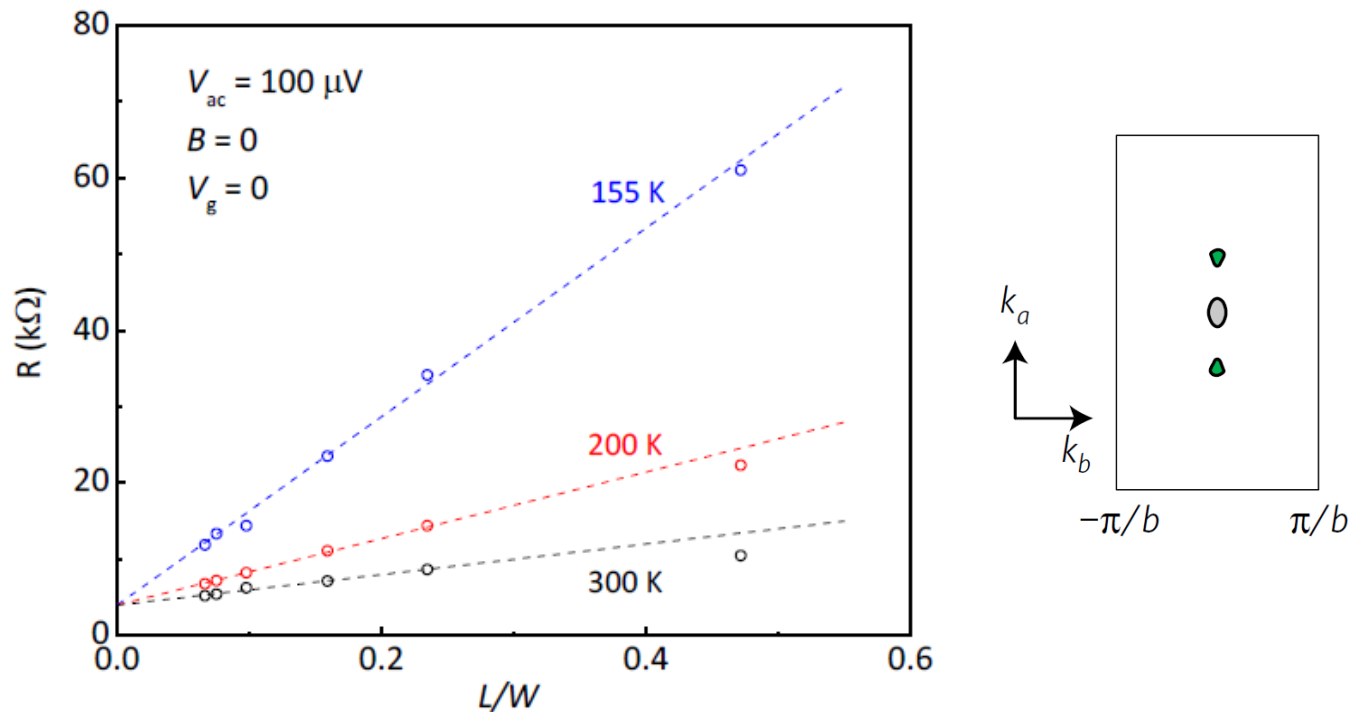


Figure S5 | Length dependence of two-terminal resistance in device MW1. Resistance as a function of aspect ratio at $V_g = 0$ for $T = 300$ K, 200 K, and 155 K.

SI-5. Temperature dependence of the monolayer 2D bulk conduction

Figure S6a shows two-terminal linear-response conductance measurements in device MW2 made in a similar way to the measurements on the pincer-shaped device (MW3) in the main text (Fig. 2). Again a conductance plateau is seen at 4.2 K with mesoscopic fluctuations, indicating there is only edge conduction in this region. The conductance of the plateau is relatively low because of the combination of longer edges and ZBA. When we short out all the edge current, as shown in the insets, the conductance I/V is suppressed to an unmeasurably small level in the plateau region implying that the conductance through the bulk is negligible at this temperature. Figure S6b shows its temperature dependence at $V_g = 0$. Above ~ 100 K, the conductance rises roughly linearly with temperature. At lower temperatures, it is approximately activated with activation energy ~ 5 meV (red trace in the right inset). This illustrates the sense in which the bulk becomes insulating below 100 K.

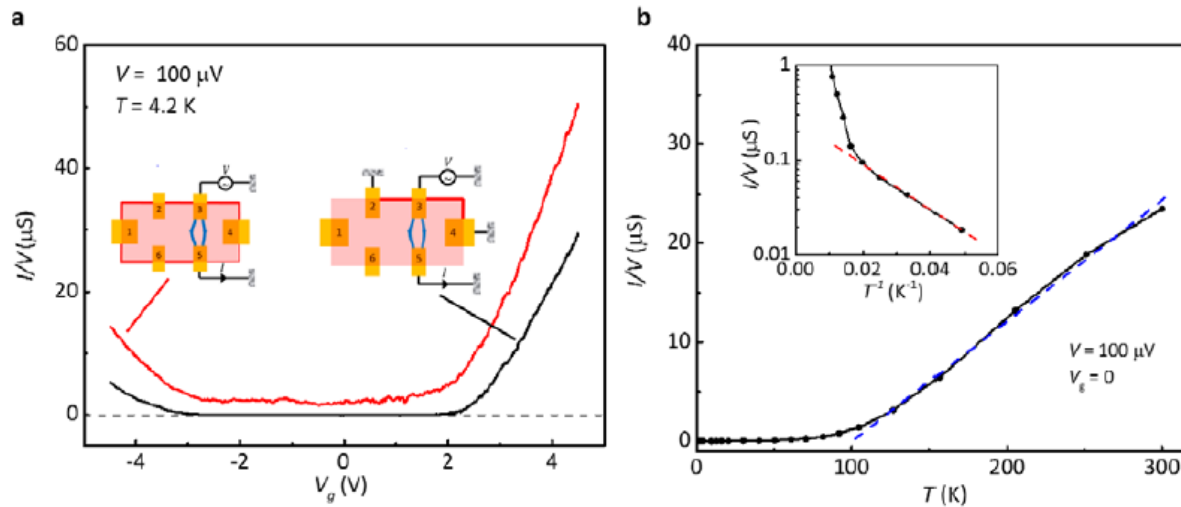


Figure S6 | Gate and temperature dependence of bulk conductance in device MW2. a, Comparison of I/V as a function of gate voltage for the two experimental configurations shown. Analogous to Fig. 2c in the main text, the red trace is the total two-terminal resistance which contains both edge and bulk contributions, while the black trace only contains a bulk contribution. **b,** Temperature dependence of the bulk measurement at $V_g = 0$. Inset: Arrhenius plot, showing approximately activated behavior below ~ 100 K (red trace, 5 meV). No signal was detectable above the background noise at temperatures below the lowest one shown here (20 K).