# tbg_rot_figures

February 23, 2021

## 1 Introduction

This Jupyter notebook loads data and generates figures from:

**Evidence of orbital ferromagnetism in twisted bilayer graphene aligned to hexagonal boron nitride**

Authors: Aaron L. Sharpe, Eli J. Fox, Arthur W. Barnard, Joe Finney, Kenji Watanabe, Takashi Taniguchi, M. A. Kastner, David Goldhaber-Gordon

[1]:
```
import sys
print(sys.version)
```

```
3.8.5 (default, Sep  3 2020, 21:29:08) [MSC v.1916 64 bit (AMD64)]
```

## 2 Initialization

[2]:
```
import json
from cycler import cycler
import numpy as np
import matplotlib.pyplot as plt
%matplotlib inline
```

[3]:
```
# Set default plotting parameters

plt.rcParams['axes.prop_cycle'] = cycler(
    color=['#E24A33', '#348ABD', '#988ED5', '#777777',
           '#FBC15E', '#8EBA42', '#FFB5B8'])

plt.rcParams['axes.linewidth'] = 1
plt.rcParams['xtick.direction'] = 'in'
plt.rcParams['xtick.top'] = 'True'
plt.rcParams['xtick.major.size'] = 5
plt.rcParams['xtick.major.width'] = 1
plt.rcParams['xtick.minor.size'] = 2.5
plt.rcParams['xtick.minor.width'] = 1

plt.rcParams['ytick.direction'] = 'in'
plt.rcParams['ytick.right'] = 'True'
```

```
plt.rcParams['ytick.major.size'] = 5
plt.rcParams['ytick.major.width'] = 1
plt.rcParams['ytick.minor.size'] = 2.5
plt.rcParams['ytick.minor.width'] = 1

plt.rcParams['lines.linewidth'] = 1.5
plt.rcParams['font.size'] = 12
plt.rcParams['axes.labelsize'] = 12
```

## 3 Load data

[4]:
```
def import_data(file):
    with open(file, 'r') as f:
        json_load = json.load(f)
    return json_load


fig1 = import_data('data/fig1.json')
fig2 = import_data('data/fig2.json')
fig3 = import_data('data/fig3.json')

figs2 = import_data('data/figs2.json')
figs3 = import_data('data/figs3.json')
figs4 = import_data('data/figs4.json')
figs5a = import_data('data/figs5a.json')
figs5b = import_data('data/figs5b.json')
figs6 = import_data('data/figs6.json')
figs7 = import_data('data/figs7.json')
figs8 = import_data('data/figs8.json')
```

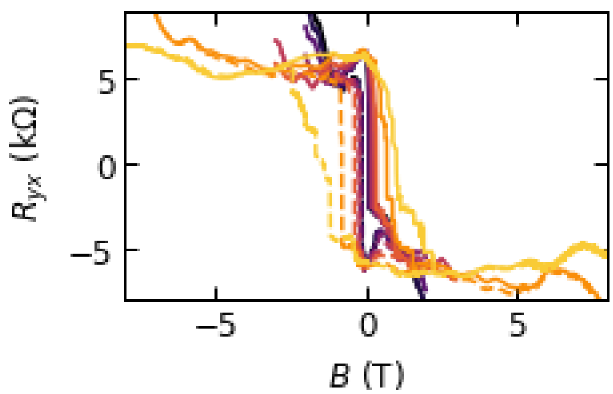
## 4 Figure 1

**Angular dependence of magnetic hysteresis loops.**

Magnetic field dependence of the Hall resistance $R_{yx}$ with $n/n_s = 0.746$ and $D/\epsilon_0 = -0.30$ V/nm at 29 mK as a function of the angle of the device relative to the field direction; 0° corresponds to field in the plane of the sample. The hysteresis loops are plotted as a function of (a) the applied field $B$ and (b) the component of the field perpendicular to the plane of the sample $B_\perp$. The solid and dashed lines correspond to sweeping the magnetic field $B$ up and down, respectively. Inset: schematic diagram displaying the components of the magnetic field $B$ at the sample (shown in purple) for a given tilt angle $\theta$

### 4.1 1A

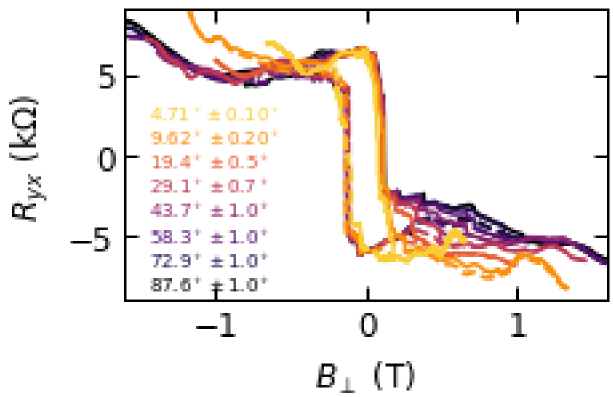
[5]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')
col = plt.get_cmap('inferno')

for i, theta in enumerate(fig1['thetas_deg']):
    plt.plot(fig1['dn_B'][i], fig1['dn_ryx'][i],
             color=col(i/len(fig1['thetas_deg'])), label=fig1['labels'][i])
    plt.plot(fig1['up_B'][i], fig1['up_ryx'][i],
             color=col(i/len(fig1['thetas_deg'])), linestyle='--')

plt.xlim(-8, 8)
plt.ylim(-8, 9)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')

plt.savefig('figures/fig1a.pdf', bbox_inches='tight', transparent=True)
```




### 4.2 1B

[6]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')
col = plt.get_cmap('inferno')

for i, theta in enumerate(fig1['thetas_deg']):
    plt.plot(np.sin(fig1['thetas'][i])*np.array(fig1['dn_B'][i]),
             fig1['dn_ryx'][i], color=col(i/len(fig1['thetas_deg'])),␣
↪label=fig1['labels'][i])
    plt.plot(np.sin(fig1['thetas'][i])*np.array(fig1['up_B'][i]),
             fig1['up_ryx'][i], color=col(i/len(fig1['thetas_deg'])),␣
↪linestyle='--')
```

```
    ax.text(0.05, 0.095+0.085*i, fig1['labels'][i],
            transform=ax.transAxes, fontsize=7, va='top', ha='left',␣
↪color=col(i/(len(fig1['thetas_deg']))))

plt.xlim(-1.6, 1.6)
plt.ylim(-9, 9)
plt.xlabel(r'$B_{\mathrm{\perp}}\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')

plt.savefig('figures/fig1b.pdf', bbox_inches='tight', transparent=True)
```




# 5 Figure 2

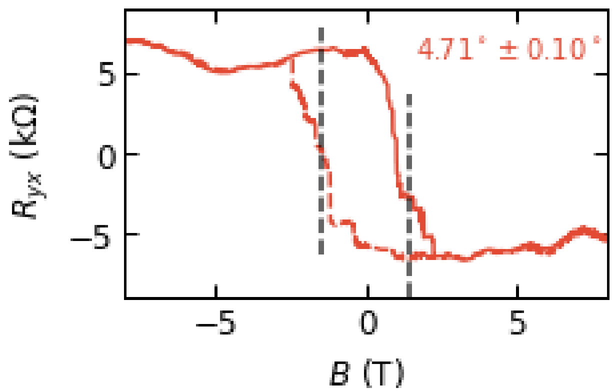
**Hysteresis loops for small tilt angles.**

Angular dependence of $R_{yx}$ vs $B$ with $n/n_s = 0.746$ and $D/\epsilon_0 = -30$ V/nm for angles of the field relative to the plane of the sample: (a) $4.71° \pm 0.10°$, (b) $1.82° \pm 0.10°$, (c) $0.85° \pm 0.10°$, (d) $+0.223° \pm 0.049°$, and $-0.171° \pm 0.025°$. Vertical dashed black lines indicate where the out-of-plane component of the field equals the coercive field ±119 mT. The out-of-plane component of the field is raised beyond the coercive field in panels (a),(b), just reaches the coercive field in (c), and does not reach it in (d). All traces were taken at 27 mK except for the trace with tilt angle $+0.223° \pm 0.049°$, which was taken at 1.35 K.

## 5.1 2A

[7]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')

ind = 0
plt.plot(fig2['dn_B'][ind], fig2['dn_ryx'][ind],
         color='C0', label=fig2['labels'][ind])
plt.plot(fig2['up_B'][ind], fig2['up_ryx'][ind],
```

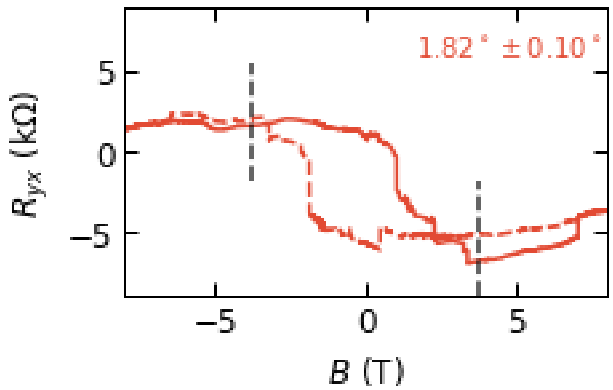
```
         color='C0', linestyle='--')
plt.xlim(-8, 8)
plt.ylim(-9, 9)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')
ax.text(0.60, 0.915, fig2['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C0')

Bc = 0.119
theta = 4.71*np.pi/180
plt.axvline( Bc/np.sin(theta), ymin=0.0, ymax=0.7, color='k', linestyle='--',␣
 ↪alpha=0.8)
plt.axvline(-Bc/np.sin(theta), ymin=0.15, ymax=0.93, color='k', linestyle='--',␣
 ↪alpha=0.8)

plt.savefig('figures/fig2a.pdf', bbox_inches='tight', transparent=True)
```




### 5.2 2B

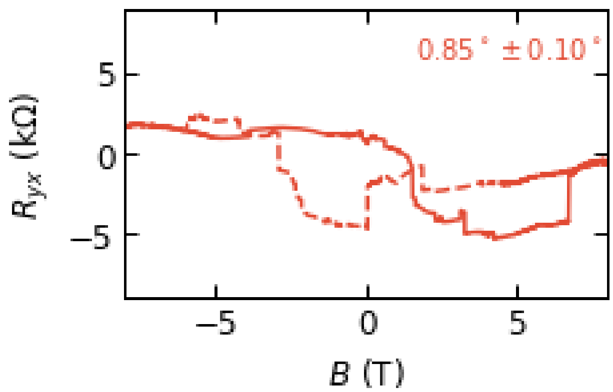
[8]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')

ind = 1
plt.plot(fig2['dn_B'][ind], fig2['dn_ryx'][ind],
         color='C0', label=fig2['labels'][ind])
plt.plot(fig2['up_B'][ind], fig2['up_ryx'][ind],
         color='C0', linestyle='--')
plt.xlim(-8, 8)
plt.ylim(-9, 9)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')
ax.text(0.60, 0.915, fig2['labels'][ind],
```

```
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C0')

Bc = 0.119
theta = 1.82*np.pi/180
plt.axvline( Bc/np.sin(theta), ymin=0.0, ymax=0.4, color='k', linestyle='--',␣
 ↪alpha=0.8)
plt.axvline(-Bc/np.sin(theta), ymin=0.4, ymax=0.8, color='k', linestyle='--',␣
 ↪alpha=0.8)

plt.savefig('figures/fig2b.pdf', bbox_inches='tight', transparent=True)
```



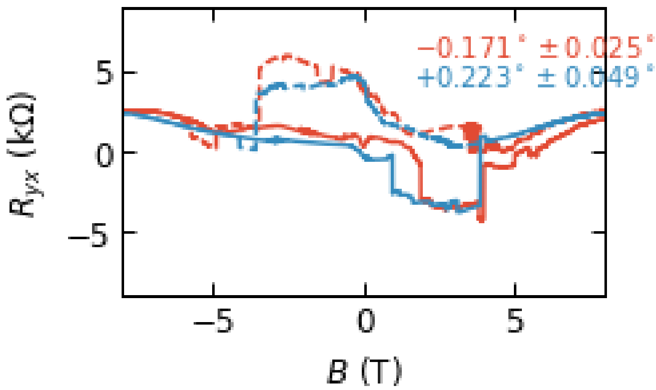

### 5.3 2C

[9]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')

ind = 2
plt.plot(fig2['dn_B'][ind], fig2['dn_ryx'][ind],
         color='C0', label=fig2['labels'][ind])
plt.plot(fig2['up_B'][ind], fig2['up_ryx'][ind],
         color='C0', linestyle='--')
plt.xlim(-8, 8)
plt.ylim(-9, 9)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')
ax.text(0.60, 0.915, fig2['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C0')

plt.savefig('figures/fig2c.pdf', bbox_inches='tight', transparent=True)
```




### 5.4 2D

[10]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')

ind = 3
plt.plot(fig2['dn_B'][ind], fig2['dn_ryx'][ind],
         color='C0', label=fig2['labels'][ind])
plt.plot(fig2['up_B'][ind], fig2['up_ryx'][ind],
         color='C0', linestyle='--')

ind = 4
plt.plot(fig2['dn_B'][ind], fig2['dn_ryx'][ind],
         color='C1', label=fig2['labels'][ind])
plt.plot(fig2['up_B'][ind], fig2['up_ryx'][ind],
         color='C1', linestyle='--')

plt.xlim(-8, 8)
plt.ylim(-9, 9)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')

ind = 3
ax.text(0.60, 0.915, fig2['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C0')
ind = 4
ax.text(0.60, 0.815, fig2['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C1')

plt.savefig('figures/fig2b.pdf', bbox_inches='tight', transparent=True)
```

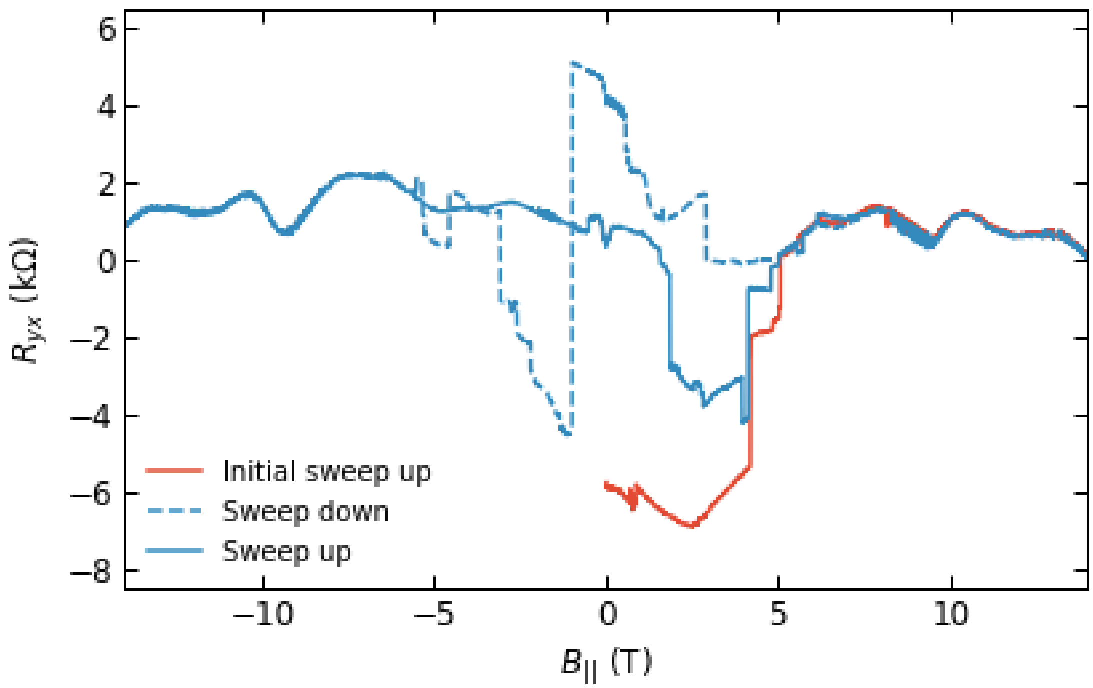



## 6 Figure 3

**Erasing the initial magnetic state.**

In-plane hysteresis loops of $R_{yx}$ with $n/n_s = 0.746$ and $D/\epsilon_0 = -30$ V/nm at 26 mK. The sample is initially polarized with an out-of-plane field. The sample is then rotated to $-57 \pm 21$ mdeg in zero magnetic field. The in-plane magnetic field $B_{||}$ is then increased from zero (red trace) before completing a hysteresis loop (blue solid and dashed traces).

[11]:
```
fig, ax = plt.subplots(figsize=(4*1.618, 4))
fig.patch.set_facecolor('white')

plt.plot(np.cos(fig3['thetas'][0])*np.array(fig3['dn_B'][0]),
         fig3['dn_ryx'][0], label='Initial sweep up')
plt.plot(np.cos(fig3['thetas'][0])*np.array(fig3['dn_B'][1]),
         fig3['dn_ryx'][1], color='C0')
plt.plot(np.cos(fig3['thetas'][0])*np.array(fig3['up_B'][0]),
         fig3['up_ryx'][0], linestyle='--', label='Sweep down')
plt.plot(np.cos(fig3['thetas'][0])*np.array(fig3['dn_B'][2]),
         fig3['dn_ryx'][2], color='C1', label='Sweep up')
plt.plot(np.cos(fig3['thetas'][0])*np.array(fig3['dn_B'][3]),
         fig3['dn_ryx'][3], color='C1')

plt.xlim(-14, 14)
plt.ylim(-8.5, 6.5)
plt.xlabel(r'$B_{||}\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')
plt.legend(fontsize=10, frameon=False, loc='lower left')

plt.savefig('figures/fig3_raw.pdf', bbox_inches='tight', transparent=True)
```




# 7 Figure S2

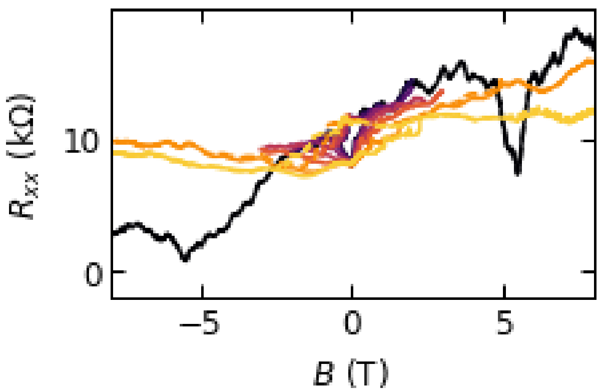
**Angular dependence of longitudinal Resistance in magnetic hysteresis loops.**

Magnetic field dependence of the longitudinal resistance $R_{xx}$ corresponding to the data shown in Fig. 1 of the main text, with $n/n_s = 0.746$ and $D/\epsilon_0 = -0.30$ V/nm at 29 mK as a function of the angle of the device relative to the field direction; 0° corresponds to field in the plane of the sample. The hysteresis loops are plotted as a function of (a) the applied field $B$ and (b) the component of the field perpendicular to the plane of the sample $B_\perp$. The solid and dashed lines correspond to sweeping the magnetic field $B$ up and down, respectively.

## 7.1 S2A

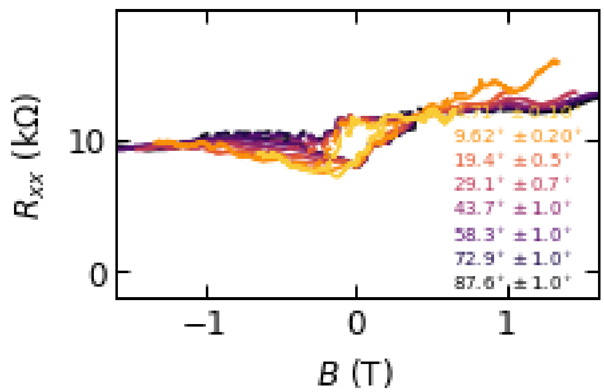
[12]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')
col = plt.get_cmap('inferno')

for i, theta in enumerate(figs2['thetas_deg']):
    plt.plot(figs2['dn_B'][i], figs2['dn_rxx'][i],
             color=col(i/len(figs2['thetas_deg'])), label=figs2['labels'][i])
    plt.plot(figs2['up_B'][i], figs2['up_rxx'][i],
             color=col(i/len(figs2['thetas_deg'])), linestyle='--')

plt.xlim(-8, 8)
```

```
plt.ylim(-2, 19.9)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{xx}\ (\mathrm{k\Omega})$')

plt.savefig('figures/figs2a.pdf', bbox_inches='tight', transparent=True)
```




### 7.2 S2B

[13]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')
col = plt.get_cmap('inferno')

for i, theta in enumerate(figs2['thetas_deg']):
    plt.plot(np.sin(figs2['thetas'][i])*np.array(figs2['dn_B'][i]),
             figs2['dn_rxx'][i], color=col(i/len(figs2['thetas_deg'])),␣
 ↪label=figs2['labels'][i])
    plt.plot(np.sin(figs2['thetas'][i])*np.array(figs2['up_B'][i]),
             figs2['up_rxx'][i], color=col(i/len(figs2['thetas_deg'])),␣
 ↪linestyle='--')
    ax.text(0.70, 0.095+0.085*i, figs2['labels'][i],
            transform=ax.transAxes, fontsize=7, va='top', ha='left',␣
 ↪color=col(i/(len(figs2['thetas_deg']))))

plt.xlim(-1.6, 1.6)
plt.ylim(-2, 19.9)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{xx}\ (\mathrm{k\Omega})$')

plt.savefig('figures/figs2a.pdf', bbox_inches='tight', transparent=True)
```




# 8 Figure S3

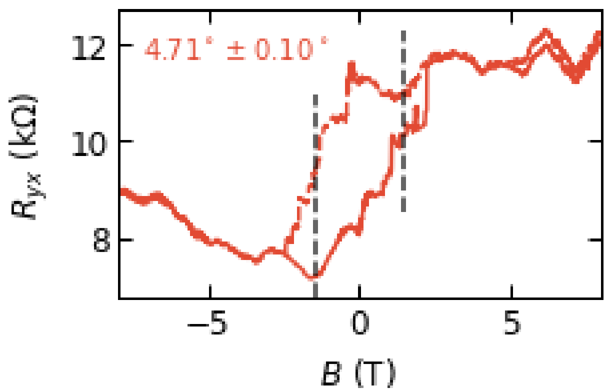
**Longitudinal resistance hysteresis loops for nearly in-plane fields.**

Angular dependence of the longitudinal resistance $R_{xx}$ vs $B$ corresponding to the data shown in Fig.~2 of the main text with $n/n_s = 0.746$ and $D/\epsilon_0 = -30$ V/nm for angles of the field relative to the plane of the sample: (a) $4.71° \pm 0.10°$, (b) $1.82° \pm 0.10°$, (c) $0.85° \pm 0.10°$, (d) $+0.223° \pm 0.049°$, and $-0.171° \pm 0.025°$. Vertical dashed black lines indicate where the out-of-plane component of the field equals the coercive field ±119 mT. The out-of-plane component of the field is raised beyond the coercive field in panels (a),(b), just reaches the coercive field in (c), and does not reach it in (d). All traces were taken at 27 mK except for the trace with tilt angle $+0.223° \pm 0.049°$, which was taken at 1.35 K.

## 8.1 S3A

[14]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')

ind = 0
plt.plot(figs3['dn_B'][ind], figs3['dn_rxx'][ind],
         color='C0', label=figs3['labels'][ind])
plt.plot(figs3['up_B'][ind], figs3['up_rxx'][ind],
         color='C0', linestyle='--')

plt.xlim(-8, 8)
plt.ylim(6.75, 12.75)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')
ax.text(0.05, 0.915, figs3['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C0')

Bc = 0.119
```

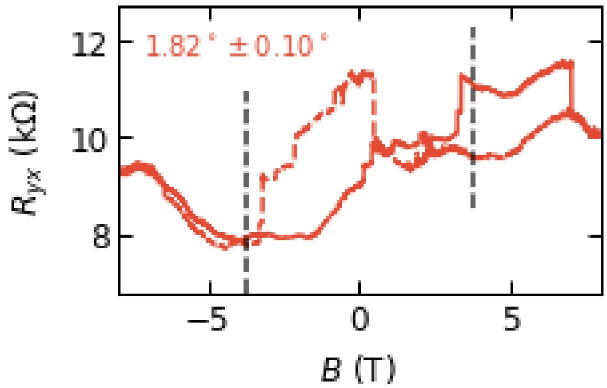
```
theta = 4.71*np.pi/180
plt.axvline( Bc/np.sin(theta), ymin=0.3, ymax=0.92, color='k', linestyle='--',␣
↪alpha=0.8)
plt.axvline(-Bc/np.sin(theta), ymin=0.00, ymax=0.7, color='k', linestyle='--',␣
↪alpha=0.8)

plt.savefig('figures/figs3a.pdf', bbox_inches='tight', transparent=True)
```




## 8.2 S3B

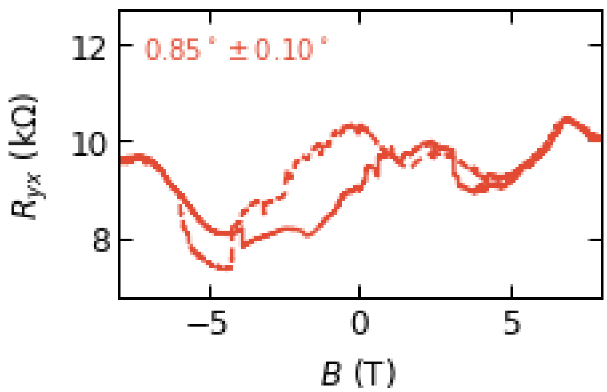
[15]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')

ind = 1
plt.plot(figs3['dn_B'][ind], figs3['dn_rxx'][ind],
         color='C0', label=figs3['labels'][ind])
plt.plot(figs3['up_B'][ind], figs3['up_rxx'][ind],
         color='C0', linestyle='--')

plt.xlim(-8, 8)
plt.ylim(6.75, 12.75)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')
ax.text(0.05, 0.915, figs3['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C0')

Bc = 0.119
theta = 1.82*np.pi/180
plt.axvline( Bc/np.sin(theta), ymin=0.3, ymax=0.92, color='k', linestyle='--',␣
↪alpha=0.8)
plt.axvline(-Bc/np.sin(theta), ymin=0.00, ymax=0.7, color='k', linestyle='--',␣
↪alpha=0.8)
```

```
plt.savefig('figures/figs3b.pdf', bbox_inches='tight', transparent=True)
```



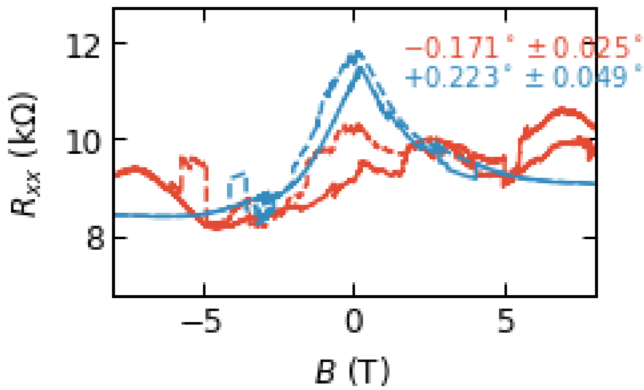

## 8.3 S3C

[16]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')

ind = 2
plt.plot(figs3['dn_B'][ind], figs3['dn_rxx'][ind],
         color='C0', label=figs3['labels'][ind])
plt.plot(figs3['up_B'][ind], figs3['up_rxx'][ind],
         color='C0', linestyle='--')

plt.xlim(-8, 8)
plt.ylim(6.75, 12.75)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')
ax.text(0.05, 0.915, figs3['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C0')

plt.savefig('figures/figs3c.pdf', bbox_inches='tight', transparent=True)
```




## 8.4 S3D

[17]:
```
fig, ax = plt.subplots(figsize=(2*1.618, 2))
fig.patch.set_facecolor('white')

ind = 3
plt.plot(figs3['dn_B'][ind], figs3['dn_rxx'][ind],
         color='C0', label=figs3['labels'][ind])
plt.plot(figs3['up_B'][ind], figs3['up_rxx'][ind],
         color='C0', linestyle='--')

ind = 4
plt.plot(figs3['dn_B'][ind], figs3['dn_rxx'][ind],
         color='C1', label=figs3['labels'][ind])
plt.plot(figs3['up_B'][ind], figs3['up_rxx'][ind],
         color='C1', linestyle='--')

plt.xlim(-8, 8)
plt.ylim(6.75, 12.75)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{xx}\ (\mathrm{k\Omega})$')

ind = 3
ax.text(0.60, 0.915, figs3['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C0')
ind = 4
ax.text(0.60, 0.815, figs3['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C1')

plt.savefig('figures/figs3d.pdf', bbox_inches='tight', transparent=True)
```

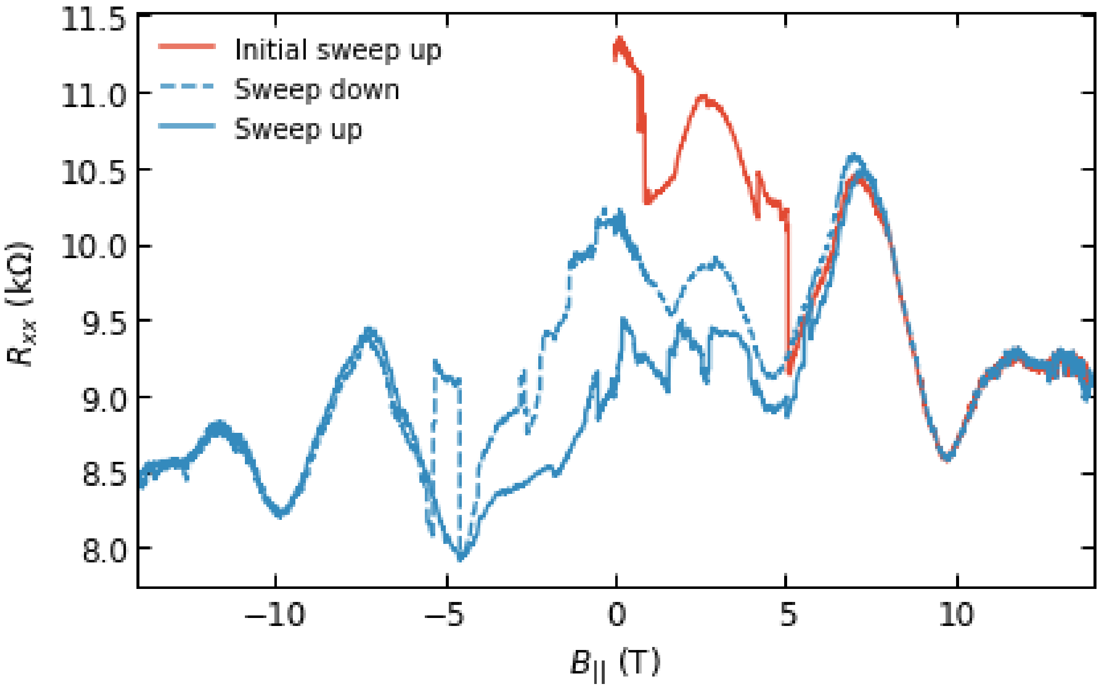



## 9 Figure S4

**Longitudinal resistance under an in-plane field from an initially magnetized state.**

In-plane hysteresis loops of the (a) longitudinal resistance $R_{xx}$ corresponding to the data shown in Fig. 3 of the main text with $n/n_s = 0.746$ and $D/\epsilon_0 = -30$ V/nm at 26 mK. The Hall resistance data $R_{yx}$ of Fig. 3 of the main text are replicated in panel (b). The sample is initially polarized with an out-of-plane field. The sample is then rotated to $-57 \pm 21$mdeg in zero magnetic field. The field $B_{||}$ is then increased from zero (red trace) before completing a hysteresis loop (blue solid and dashed traces).

[18]:
```
fig, ax = plt.subplots(figsize=(4*1.618, 4))
fig.patch.set_facecolor('white')

plt.plot(np.cos(figs4['thetas'][0])*np.array(figs4['dn_B'][0]),
         figs4['dn_rxx'][0], label='Initial sweep up')
plt.plot(np.cos(figs4['thetas'][0])*np.array(figs4['dn_B'][1]),
         figs4['dn_rxx'][1], color='C0')
plt.plot(np.cos(figs4['thetas'][0])*np.array(figs4['up_B'][0]),
         figs4['up_rxx'][0], linestyle='--', label='Sweep down')
plt.plot(np.cos(figs4['thetas'][0])*np.array(figs4['dn_B'][2]),
         figs4['dn_rxx'][2], color='C1', label='Sweep up')
plt.plot(np.cos(figs4['thetas'][0])*np.array(figs4['dn_B'][3]),
         figs4['dn_rxx'][3], color='C1')

plt.xlim(-14, 14)
plt.xlabel(r'$B_{||}\ (\mathrm{T})$')
plt.ylabel(r'$R_{xx}\ (\mathrm{k\Omega})$')
plt.legend(fontsize=10, frameon=False, loc='upper left')

plt.savefig('figures/figs4a.pdf', bbox_inches='tight', transparent=True)
```




## 10 Figure S5

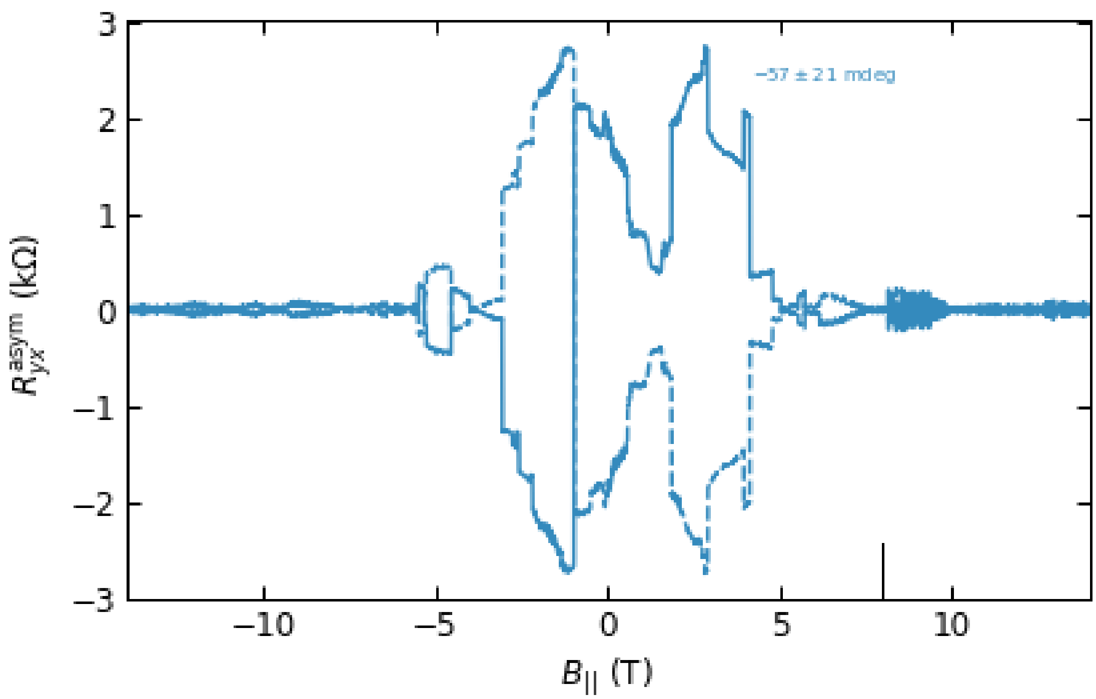
**Assymmetric contribution of the Hall resistance under an in-plane field.**

(a) Antisymmetric component of the Hall resistance $R_{yx}^{\mathrm{asym}}$ corresponding to the Hall data shown in Fig. 3 of the main text. $\pm R_{yx}^{\mathrm{asym}}$ is plotted as a solid (dashed) line. For 8 T and above (indicated by the large tick on the horizontal axis), we report $R_{yx}^{\mathrm{asym}}$ for the initial sweep up and the sweep down. Otherwise we report $R_{yx}^{\mathrm{asym}}$ for the sweep down and the sweep up (which was only completed up to 8 T.) (b) Antisymmetric component of the Hall resistance $R_{yx}^{\mathrm{asym}}$ for the nearly out-of-plane hysteresis loop performed at $87.6° \pm 1.0°$, shown in Fig. 1 of the main text. (c) Schematic diagram of the symmetrization process for an ideal hysteresis loop that is offset from zero in the vertical direction.

### 10.1 S5A

[19]:
```
fig, ax = plt.subplots(figsize=(4*1.618, 4))
fig.patch.set_facecolor('white')

plt.plot(figs5a['B_asym'], figs5a['ryx_asym'], 'C1')
plt.plot(figs5a['B_asym'], -np.array(figs5a['ryx_asym']), '--C1')
plt.plot(figs5a['B_asym_lo'], figs5a['ryx_asym_lo'], 'C1')
plt.plot(figs5a['B_asym_lo'], -np.array(figs5a['ryx_asym_lo']), '--C1')
plt.plot(figs5a['B_asym_hi'], figs5a['ryx_asym_hi'], 'C1')
plt.plot(figs5a['B_asym_hi'], -np.array(figs5a['ryx_asym_hi']), '--C1')
```

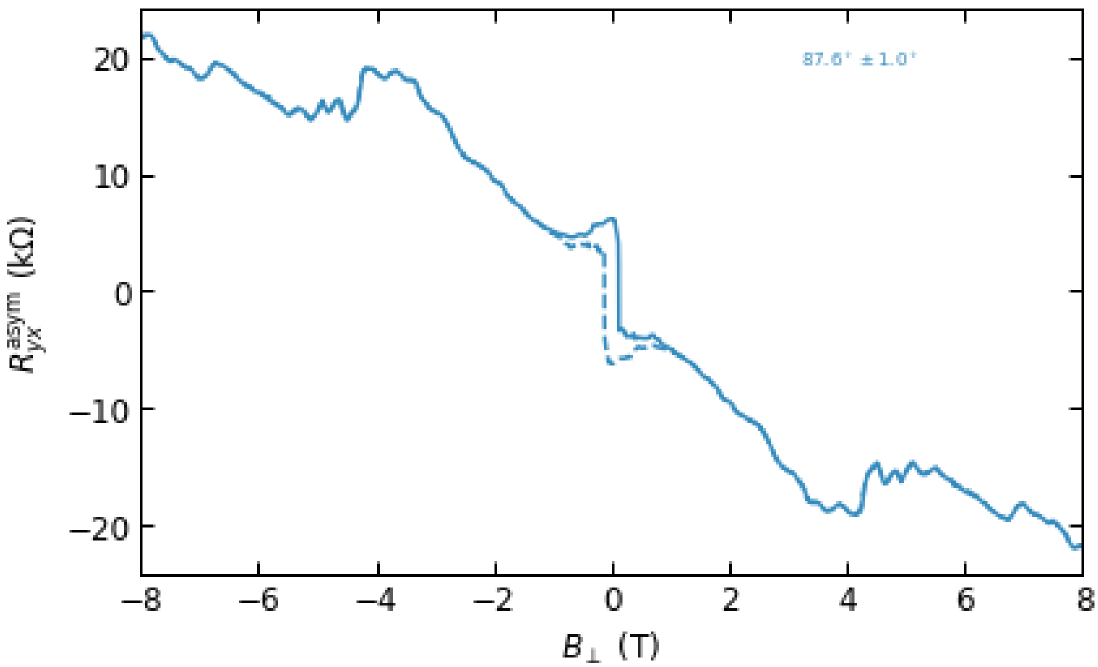
```
ax.text(0.65, 0.93, r'$-57 \pm 21\  \mathrm{mdeg}$',
        transform=ax.transAxes, fontsize=7, va='top', ha='left', color='C1')

plt.xlim(-14, 14)
plt.xlabel(r'$B_{\mathrm{||}} \ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}^{\mathrm{asym}}\ (\mathrm{k\Omega})$')

plt.axvline(8, ymin=0, ymax=0.1, color='k', linewidth=1)

plt.savefig('figures/figs5a.pdf', bbox_inches='tight', transparent=True)
```




## 10.2 S5B

[20]:
```
fig, ax = plt.subplots(figsize=(4*1.618, 4))
fig.patch.set_facecolor('white')

plt.plot(figs5b['B_asym'], figs5b['ryx_asym'], 'C1')
plt.plot(-np.array(figs5b['B_asym']), -np.array(figs5b['ryx_asym']), '--C1')

ax.text(0.70, 0.93, r'$87.6^\circ \pm 1.0^\circ$',
        transform=ax.transAxes, fontsize=7, va='top', ha='left', color='C1')
```

```python
plt.xlim(-8, 8)
plt.xlabel(r'$B_{\perp} \ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}^{\mathrm{asym}}\ (\mathrm{k\Omega})$')

plt.savefig('figures/figs5b.pdf', bbox_inches='tight', transparent=True)
```




## 11 Figure S6

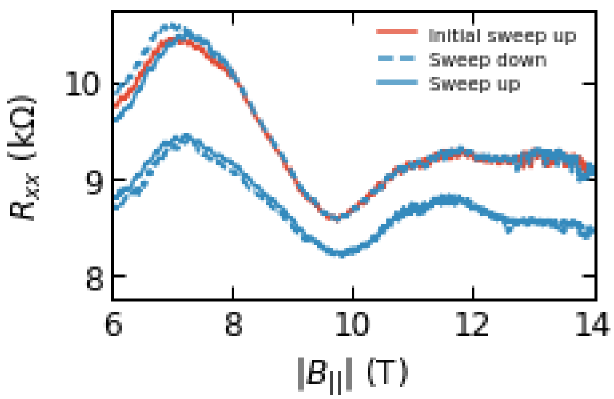
**Dependence on the magnitude of the in-plane field.**

In-plane hysteresis loops of corresponding longitudinal resistance $R_{xx}$ to the data shown in Fig. 3 of the main text with $n/n_s = 0.746$ and $D/\epsilon_0 = -30$ V/nm at 26 mK. The sample is initially polarized with an out-of-plane field. The sample is then rotated to $-57 \pm 21$ mdeg in zero magnetic field. The field $B_\parallel$ is then increased from zero (red trace) before completing a hysteresis loop (blue traces). Though the absolute resistance is offset between the two panels, as seen in the vertical axis labels, the size of the resistance range is the same in both panels.

### 11.1 S6A

[21]:
```python
fig, ax = plt.subplots(figsize = (2*1.618, 2))
fig.patch.set_facecolor('white')

plt.plot(np.cos(figs6['thetas'][0])*np.abs(figs6['dn_B'][0]),
         figs6['dn_rxx'][0], label='Initial sweep up')
plt.plot(np.cos(figs6['thetas'][0])*np.abs(figs6['dn_B'][1]),
```

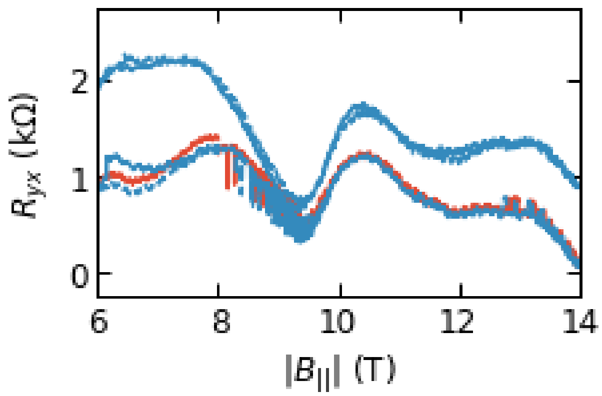
```
         figs6['dn_rxx'][1], color='C0')
plt.plot(np.cos(figs6['thetas'][0])*np.abs(figs6['up_B'][0]),
         figs6['up_rxx'][0], linestyle='--', label='Sweep down')
plt.plot(np.cos(figs6['thetas'][0])*np.abs(figs6['dn_B'][2]),
         figs6['dn_rxx'][2], color='C1', label='Sweep up')
plt.plot(np.cos(figs6['thetas'][0])*np.abs(figs6['dn_B'][3]),
         figs6['dn_rxx'][3], color='C1')

plt.xlim(6,14)
plt.ylim(7.75, 10.75)
plt.xlabel(r'$| B_{\mathrm{||}}| \ (\mathrm{T})$')
plt.ylabel(r'$R_{xx}\ (\mathrm{k\Omega})$')
plt.legend(fontsize=7, frameon=False,loc='upper right')

plt.savefig('figures/figs6a.pdf', bbox_inches='tight', transparent=True)
```




## 11.2 S6B

[22]:
```
fig, ax = plt.subplots(figsize = (2*1.618, 2))
fig.patch.set_facecolor('white')

plt.plot(np.cos(figs6['thetas'][0])*np.abs(figs6['dn_B'][0]),
         figs6['dn_ryx'][0], label='Initial sweep up')
plt.plot(np.cos(figs6['thetas'][0])*np.abs(figs6['dn_B'][1]),
         figs6['dn_ryx'][1], color='C0')
plt.plot(np.cos(figs6['thetas'][0])*np.abs(figs6['up_B'][0]),
         figs6['up_ryx'][0], linestyle='--', label='Sweep down')
plt.plot(np.cos(figs6['thetas'][0])*np.abs(figs6['dn_B'][2]),
         figs6['dn_ryx'][2], color='C1', label='Sweep up')
plt.plot(np.cos(figs6['thetas'][0])*np.abs(figs6['dn_B'][3]),
         figs6['dn_ryx'][3], color='C1')
```

```
plt.xlim(6,14)
plt.ylim(-0.25, 2.75)
plt.xlabel(r'$|B_{||}|\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')

plt.savefig('figures/figs6b.pdf', bbox_inches='tight', transparent=True)
```



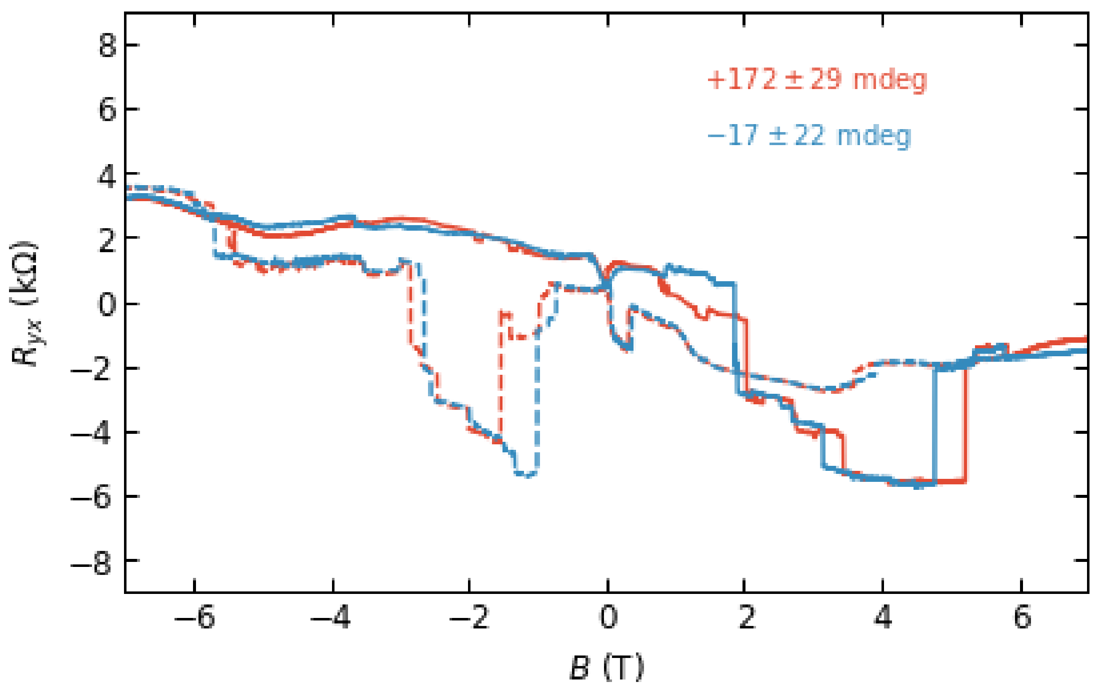

## 12 Figure S7

**Hysteresis loops at small angles.**

Magnetic field hysteresis loops where $R_{yx}$ is measured at two small angles of very different magnitude and likely opposite sign: $+172 \pm 29$ mdeg in red and $-17 \pm 22$ mdeg in blue. Both traces were taken at 28 mK with $n/n_s = 0.746$ and $D/\epsilon_0 = -30$ V/nm. The sample has been rotated in the plane by an angle of 20° relative to the measurements performed in Fig. 2 of the main text.

[23]:
```
fig, ax = plt.subplots(figsize=(4*1.618, 4))
fig.patch.set_facecolor('white')

ind = 0
plt.plot(figs7['dn_B'][ind], figs7['dn_ryx'][ind],
         color='C0', label=figs7['labels'][ind])
plt.plot(figs7['up_B'][ind], figs7['up_ryx'][ind],
         color='C0', linestyle='--')

ind = 1
plt.plot(figs7['dn_B'][ind], figs7['dn_ryx'][ind],
         color='C1', label=figs7['labels'][ind])
plt.plot(figs7['up_B'][ind], figs7['up_ryx'][ind],
         color='C1', linestyle='--')

plt.xlim(-7,7)
```

```
plt.ylim(-9,9)
plt.xlabel(r'$B\ (\mathrm{T})$')
plt.ylabel(r'$R_{yx}\ (\mathrm{k\Omega})$')

ind = 0
ax.text(0.60, 0.915, figs7['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C0')
ind = 1
ax.text(0.60, 0.815, figs7['labels'][ind],
        transform=ax.transAxes, fontsize=10, va='top', ha='left', color='C1')

plt.savefig('figures/figs7.pdf', bbox_inches='tight', transparent=True)
```



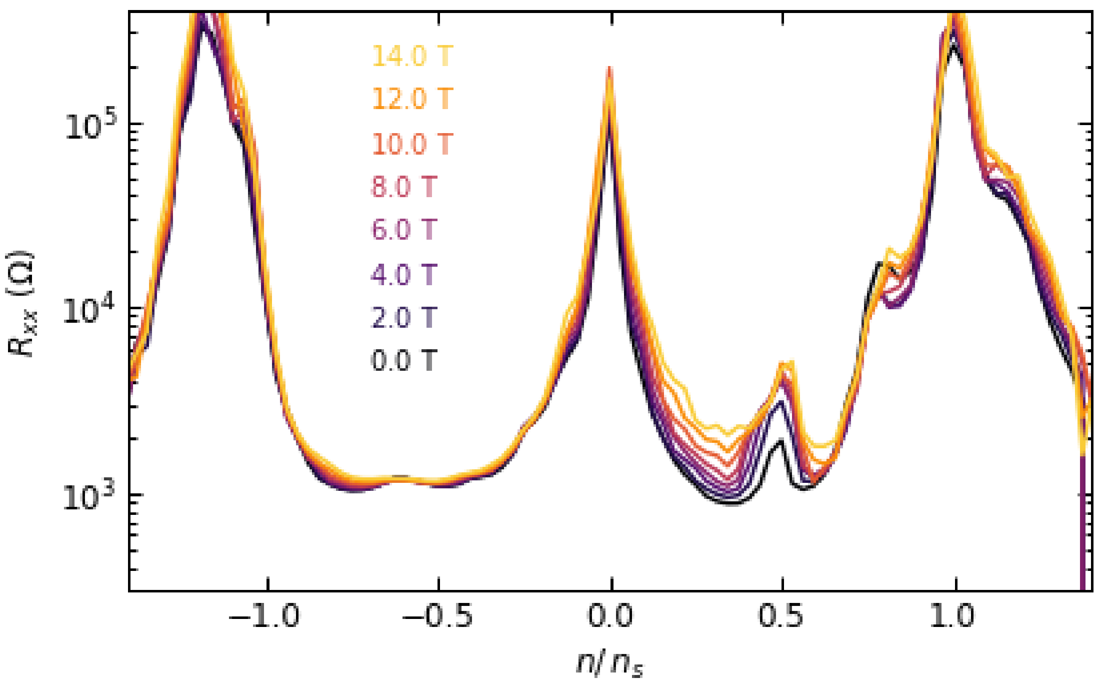

## 13 Figure S8

**In-plane field dependence of longitudinal resistance.**

Longitudinal resistance $R_{xx}$ as a function of carrier density $n$ for several different in-plane magnetic fields at a fixed displacement field of $D/\epsilon_0 = -0.30$ V/nm and 1.2 K for a tilt angle of $-62\pm23$ mdeg.

[24]:
```
fig, ax = plt.subplots(figsize = (4*1.618,4))
fig.patch.set_facecolor('white')
col = plt.get_cmap('inferno')
```

```
for i, _ in enumerate(figs8['labels']):
    fig = plt.semilogy(figs8['nu'][i], figs8['rxx'][i],
                       color=col(i/len(figs8['labels'])))
    ax.text(0.25, 0.425 + 0.075*i, figs8['labels'][i],
         transform=ax.transAxes, fontsize=10, va='top', ha='left', color=col(i/
↪len(figs8['labels'])))


plt.xlabel(r'$n/\,n_s$')
plt.ylabel(r'$R_{xx}\ (\mathrm{\Omega})$')
plt.xlim(-1.4,1.4)
plt.ylim(300,400000)

plt.savefig('figures/figs8.pdf', bbox_inches='tight', transparent=True)
```




```
[ ]:
```