Bending the QHE by 90°:

Novel 1D metallic and insulating phases

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Physica E 22, 181 (2004)
preprint

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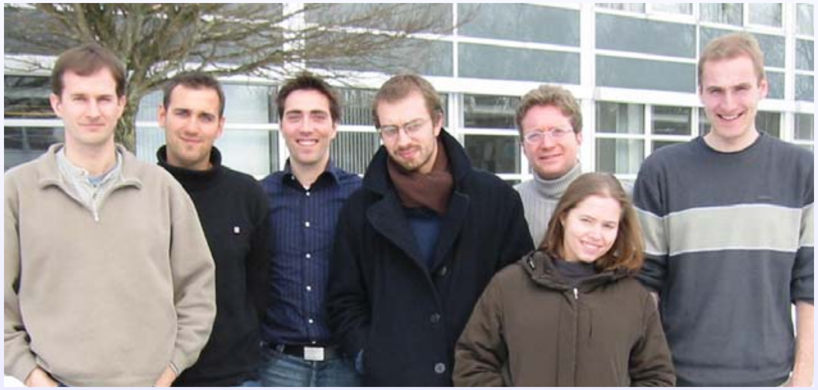
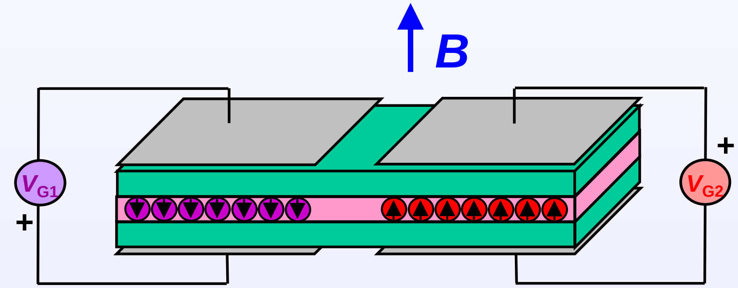
Dmitry Polyakov	*Karlsruhe Forschungszentrum*
Allan MacDonald	*University of Texas*
Eduardo Fradkin, Eun-Ah Kim	*University of Illinois*





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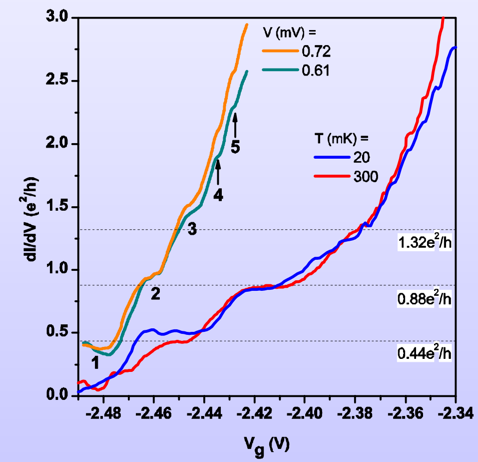
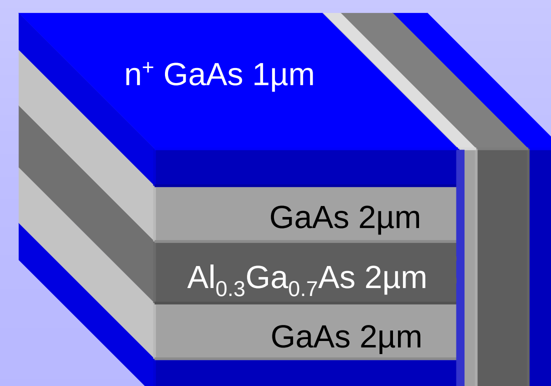
Masters: Felix Erfurth, Sebastian Jakob, Claudius Knaak, Marco Neumair



Spintronics
Heavy holes in (110) GaAs
*APL **86**, 192106 (2005)*

1D Wires
Cleaved-edge overgrown quantum wires in AlAs
*APL **87**, 052101 (2005)*

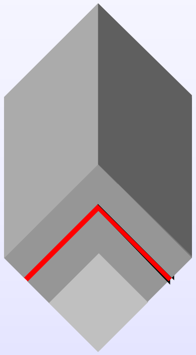
Novel Crystal Growth Techniques
MBE-Patterned Etch-Regrowth
Corner Overgrowth
*APL **86**, 032101 (2005)*



Double Cleave Quantum Wires
Modulated potential along wire

Quantum Hall Edges
Edge tunneling spectroscopy
*PRL **94**, 016805 (2005)*

Outline



Intro: QHE

I. Bent quantum well

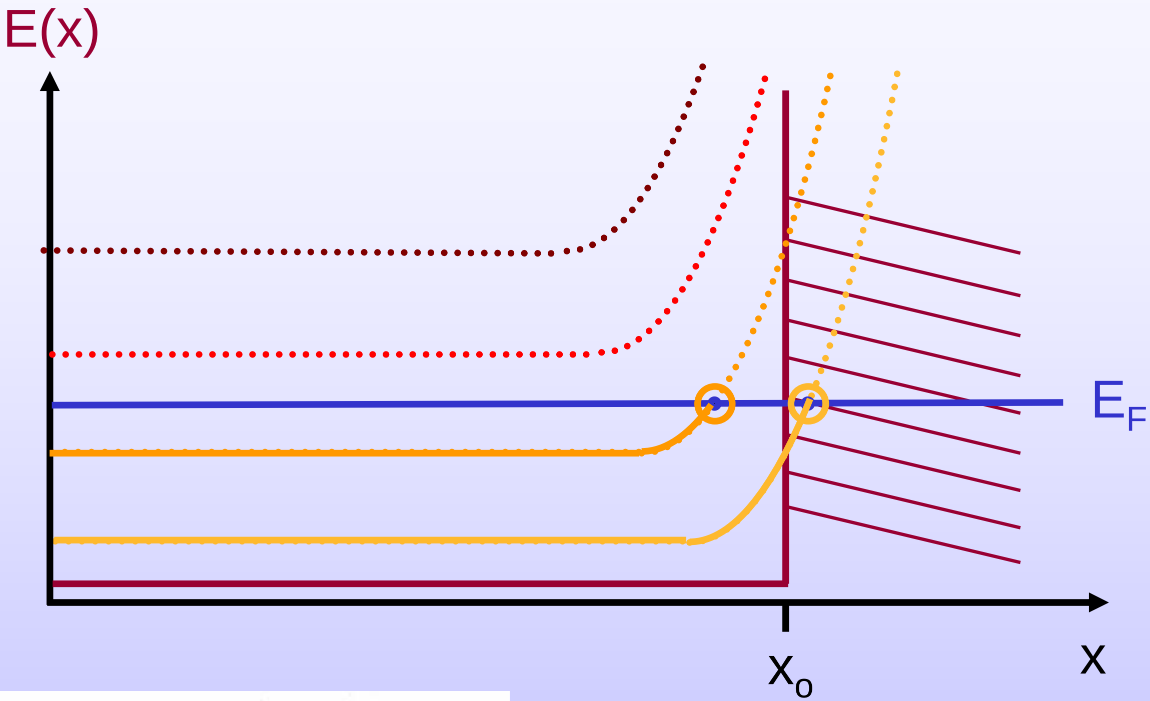
II. Bending the QHE

1D Wire bound by QHE gaps

III. T, V - dependence

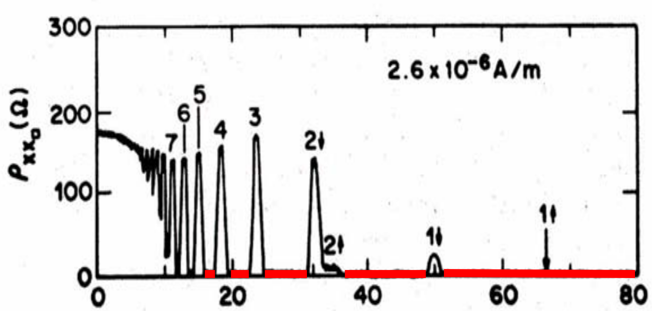
IV. Discussion + Hartree calculations

QHE Edge states



Halperin PRB (82)
Buttiker PRB (85)
X.G. Wen PRB (90)

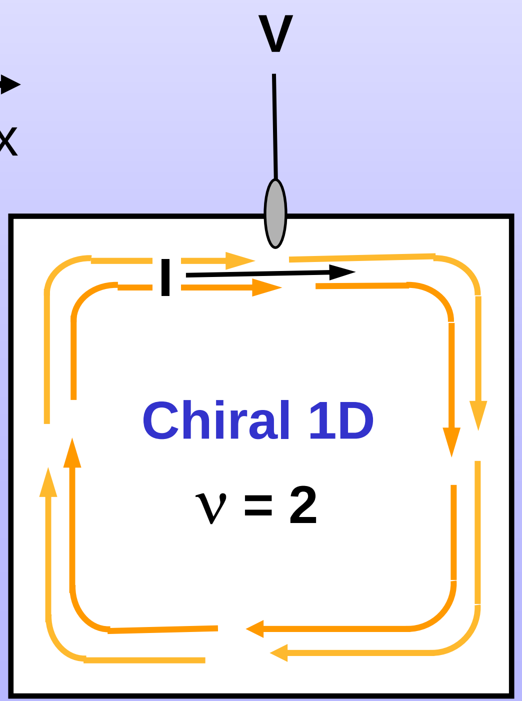
$$I = \frac{\nu e^2}{h} V$$



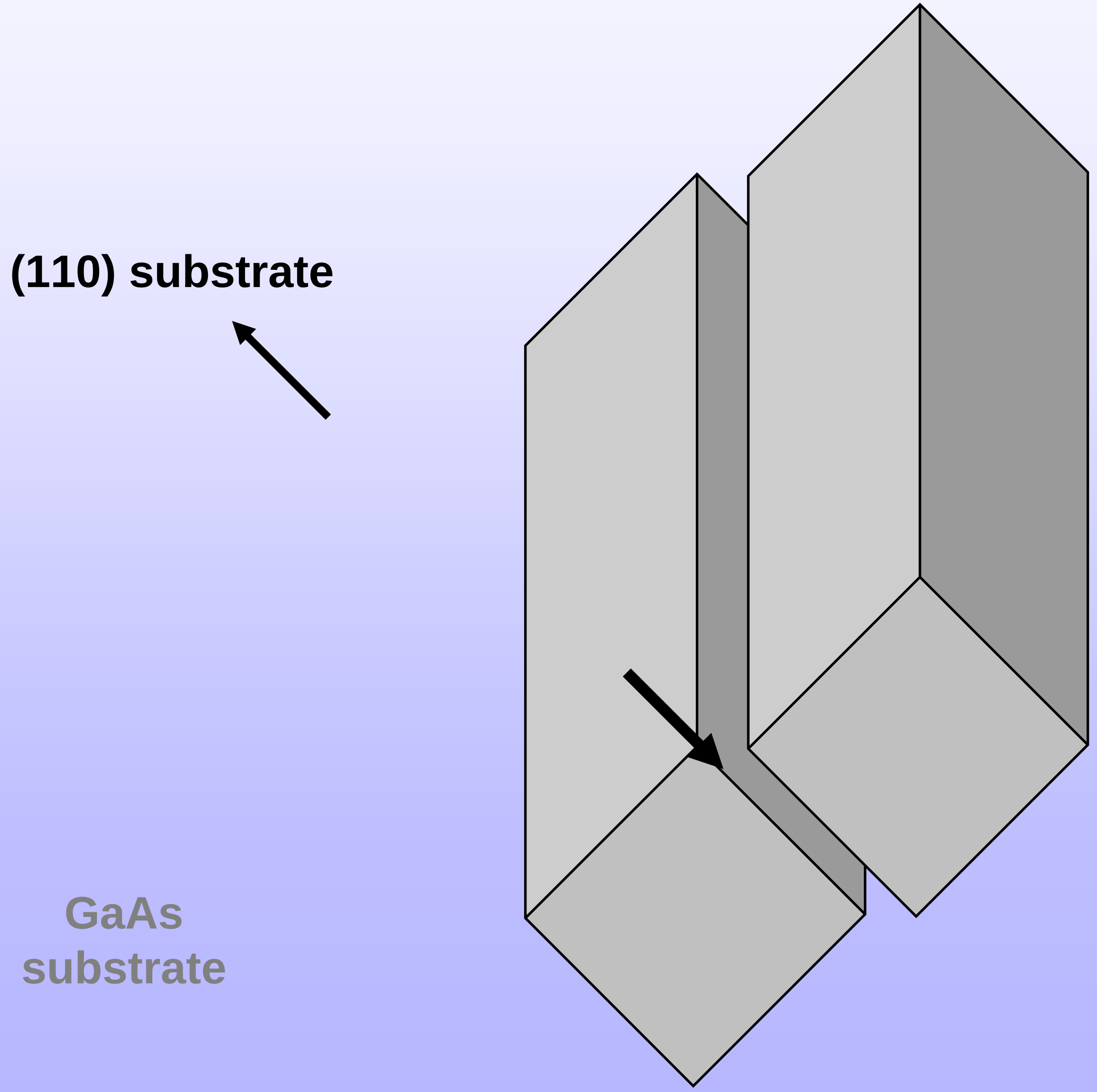
M.A. Paalanen, et al.
PRL 25 (1982)

ν = 1,2,3
 -> Fermi Liquid

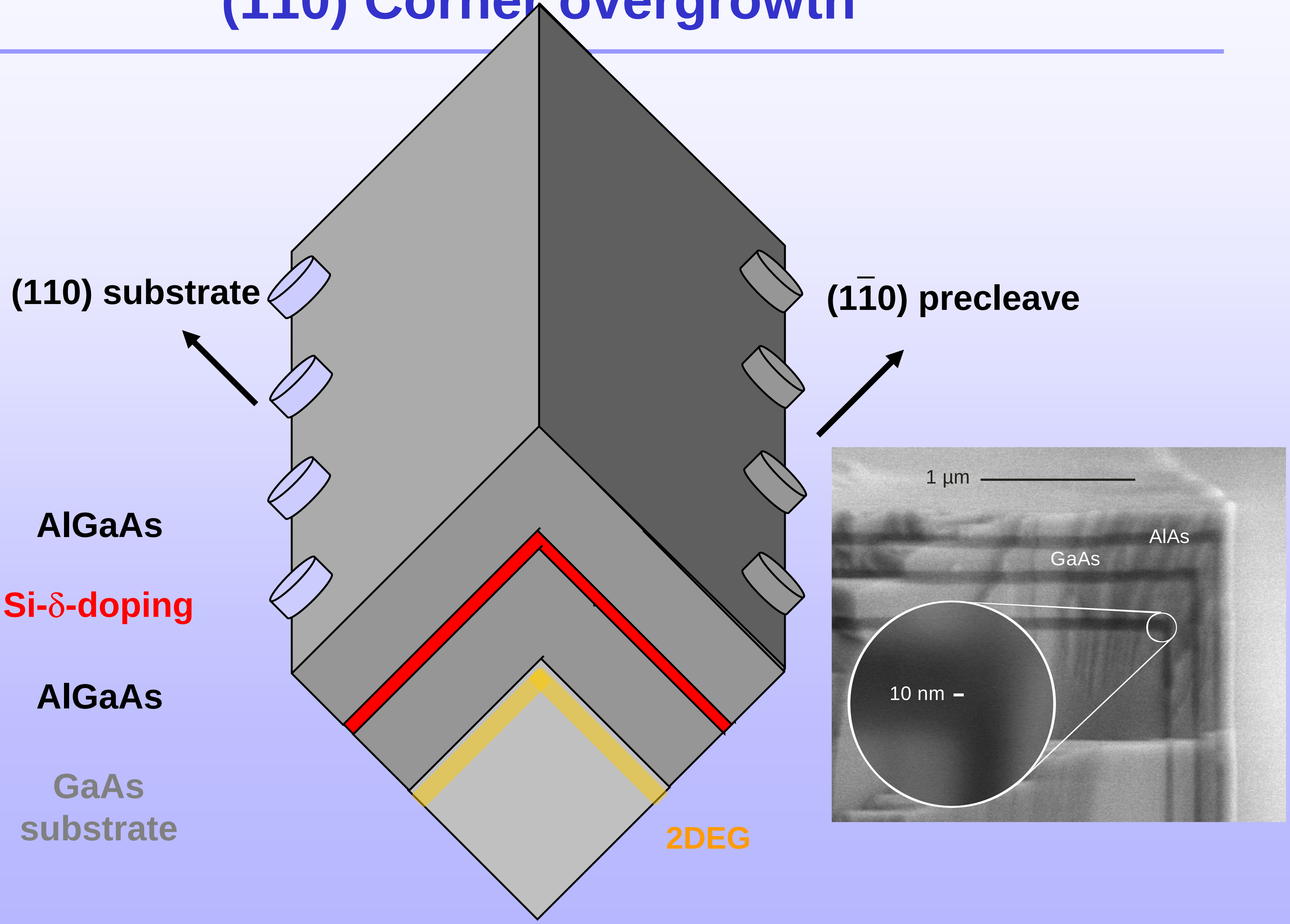
ν = 1/3
 -> Luttinger Liquid



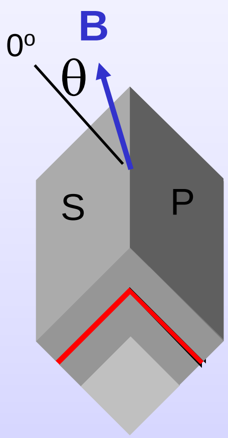
(110) Corner overgrowth

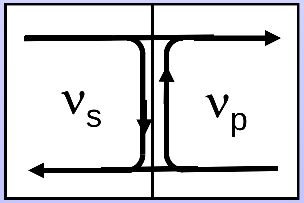


(110) Corner overgrowth

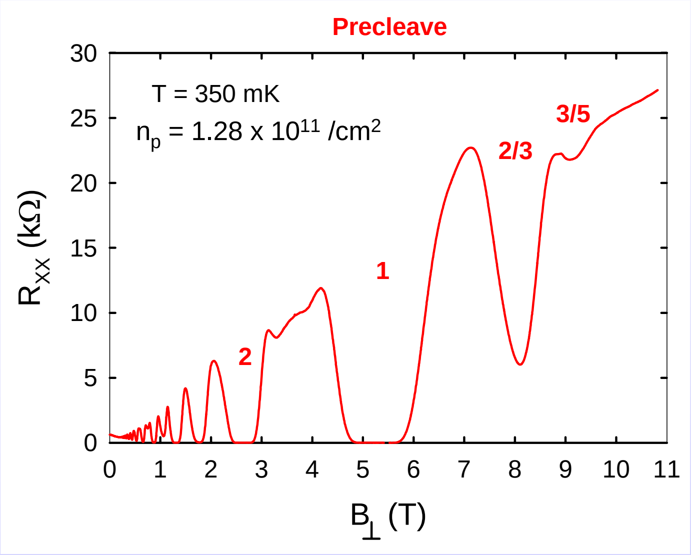


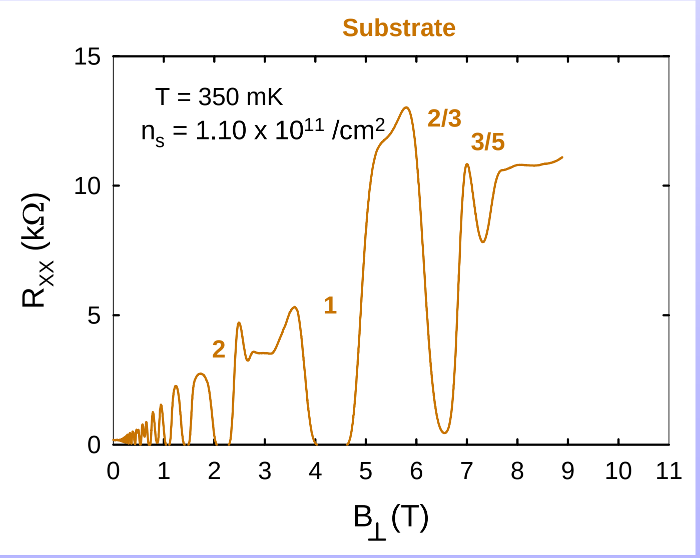
(110) Bent Quantum Well





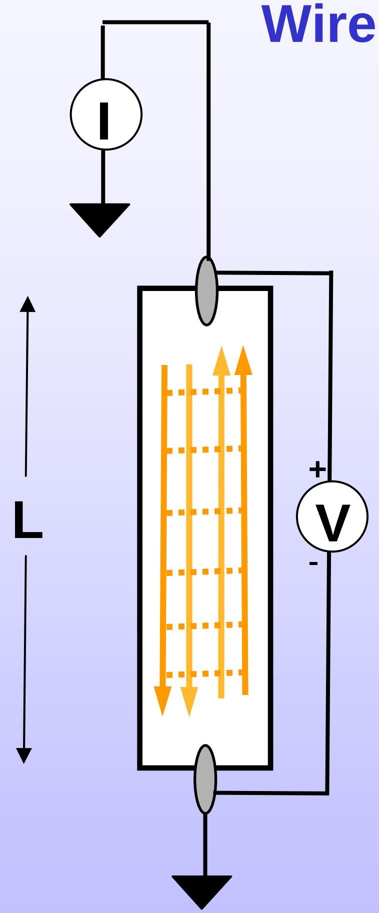
Hand-crafted in Germany





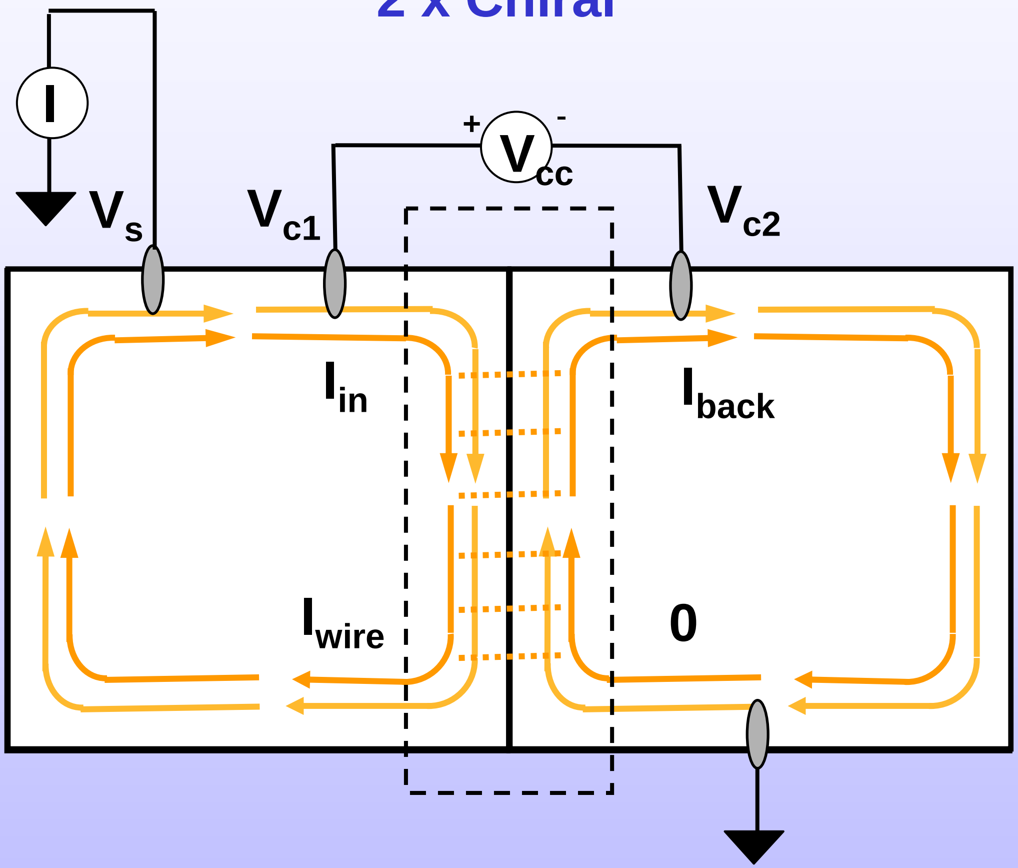
$$\frac{\nu_s}{\nu_p} = \frac{n_s / B\cos(\theta)}{n_p / B\sin(\theta)} = \frac{n_s}{n_p}\tan(\theta)$$

Example 1D Systems



$$G = I / V$$

$$\sigma_{1D} = G \cdot L$$

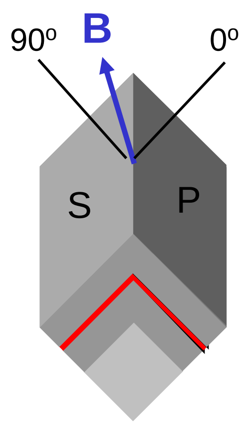


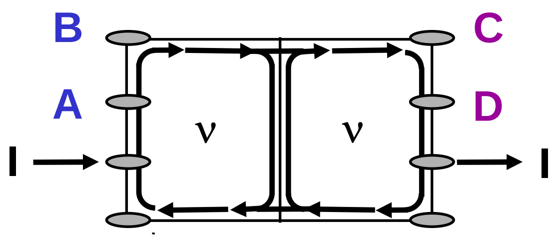
$$I_{wire} = I_{in} - I_{back} = \frac{\nu e^2}{h} V_{cc}$$

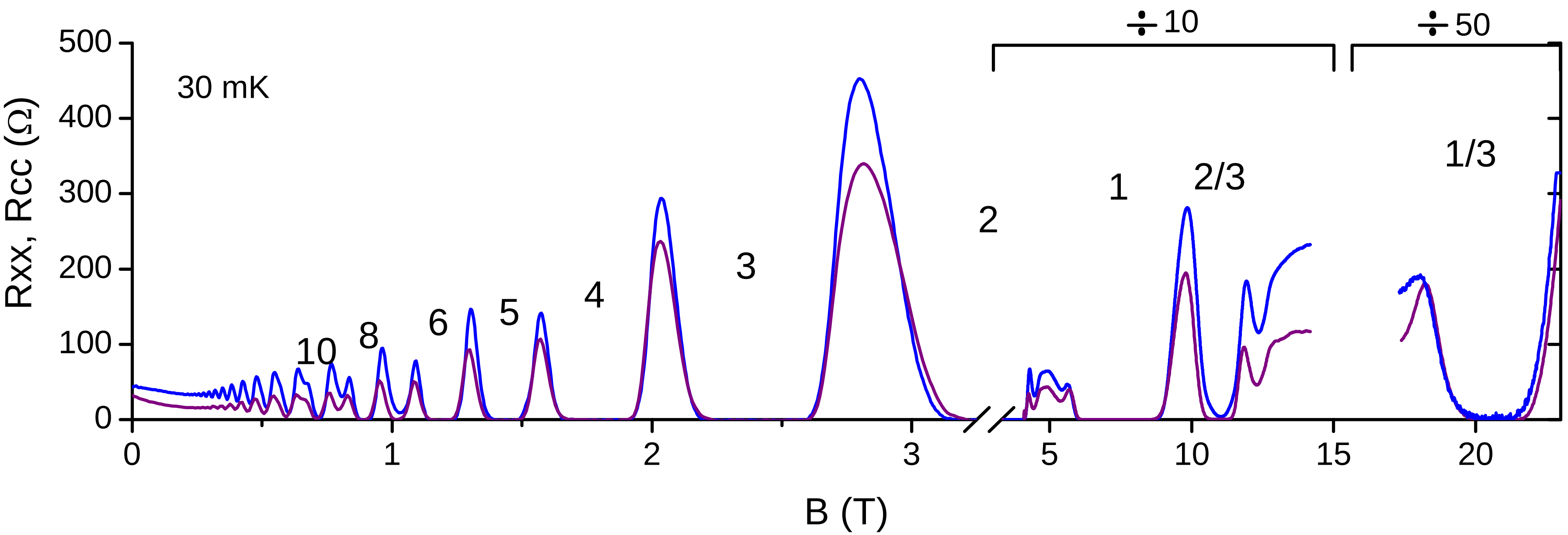
$$\boxed{G = \frac{\nu e^2}{h} \frac{V_{cc}}{V_s}}$$

Tilted field: Uniform ν

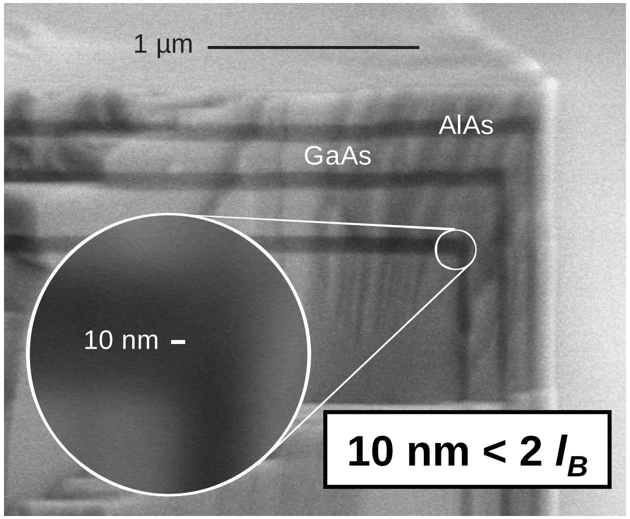
$\theta = 51.8^o$

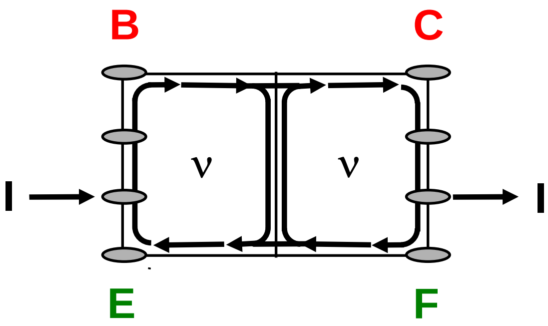




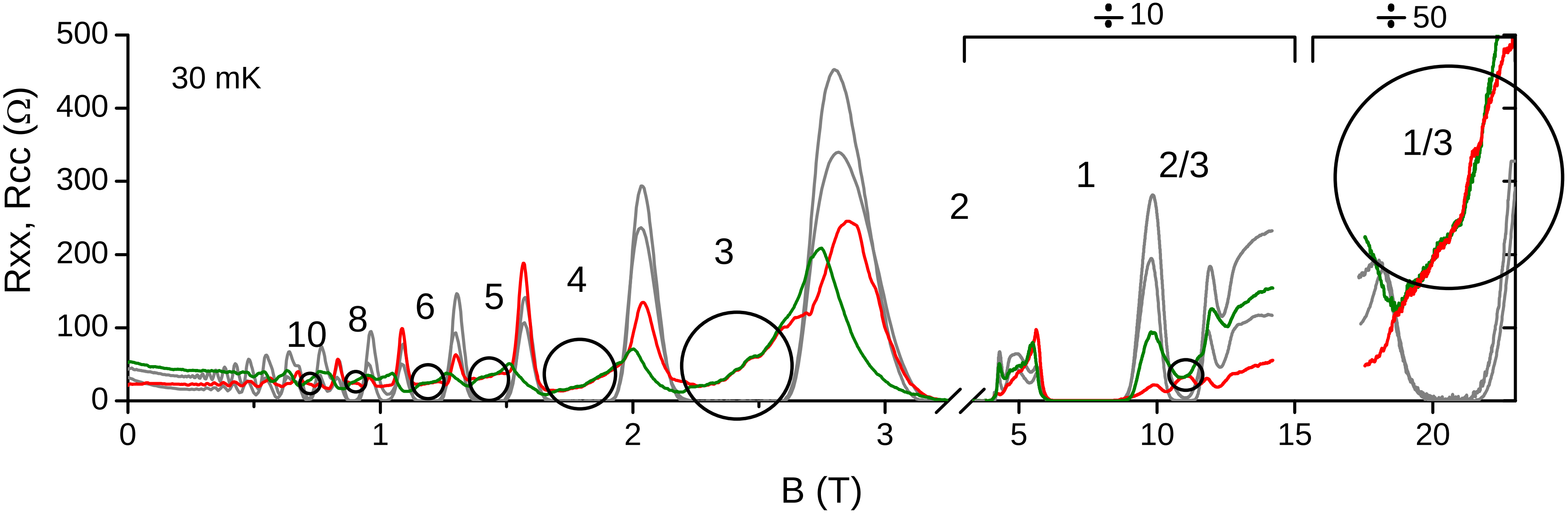


Tilted field: Uniform ν



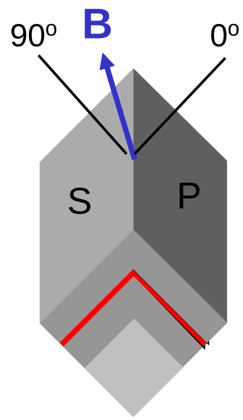


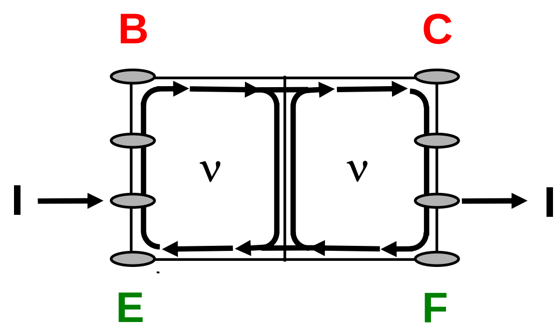
Backscattering at corner along 1D Wire



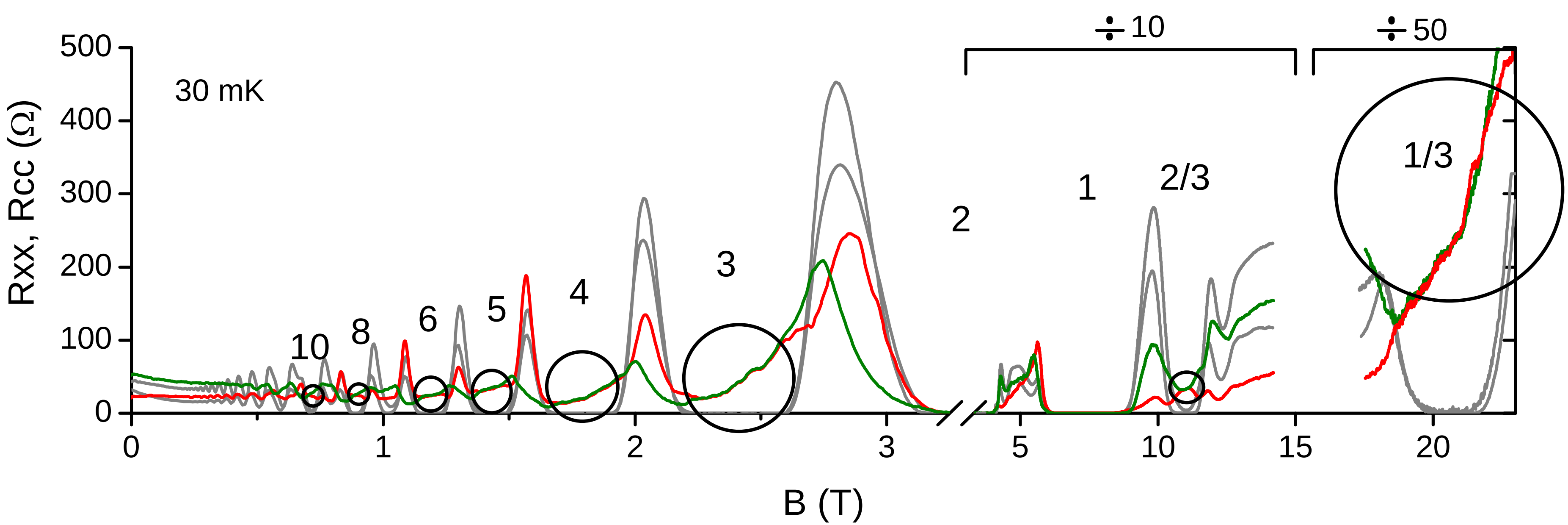
Tilted field: Uniform ν

$\theta = 51.8^o$



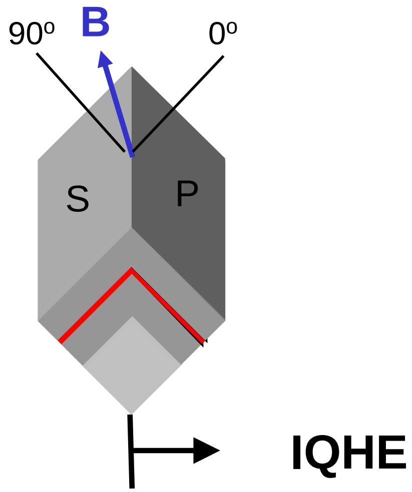


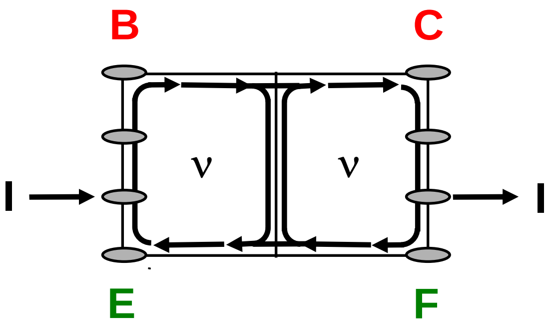
$$G = \frac{\nu e^2}{h}\frac{V_{cc}}{V_s}$$



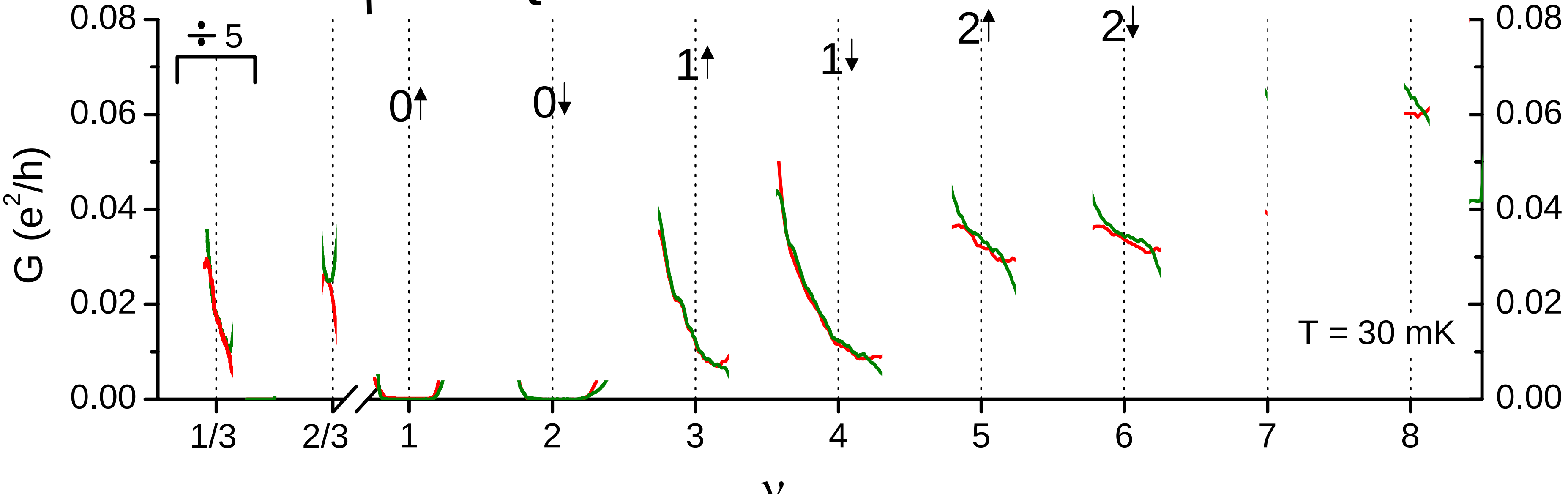
$\nu_s:\nu_p = 1:1$

$\theta = 51.8^o$

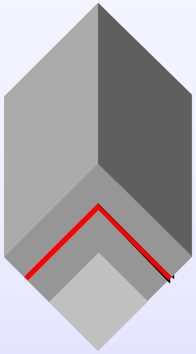




$$G = \frac{\nu e^2}{h}\frac{V_{cc}}{V_s}$$

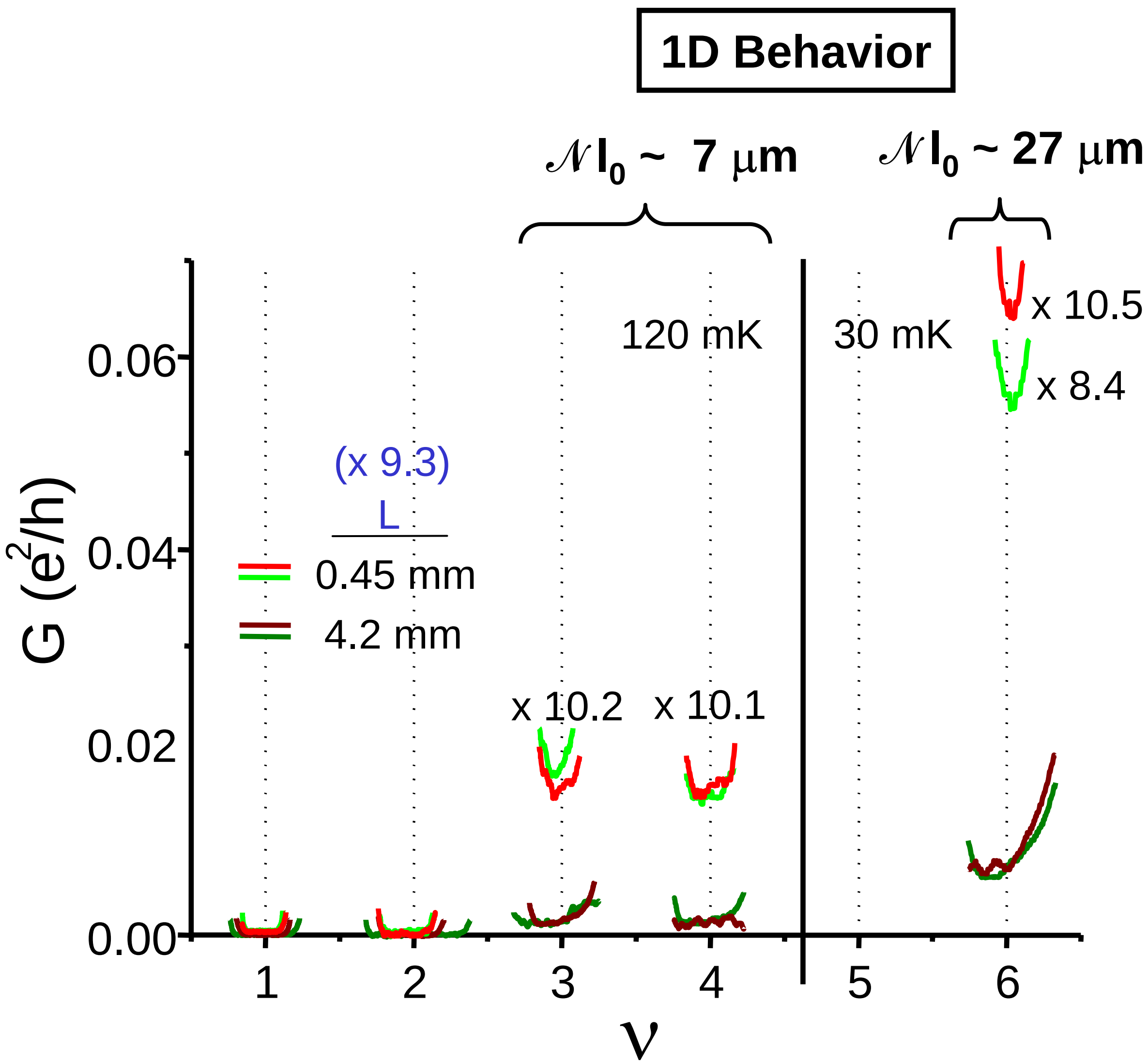


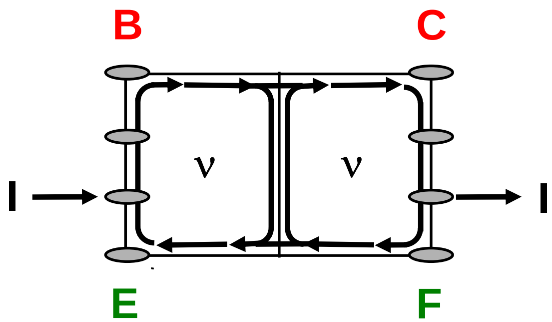
Characteristics Table



ν	*B*	conductance
1/3	20-23 T	conductor
1, 2	4-9 T	insulator
3, 4, 5, 6	0-2.5 T	conductor

Length Dependence
$\nu_s:\nu_p$ = 1:1

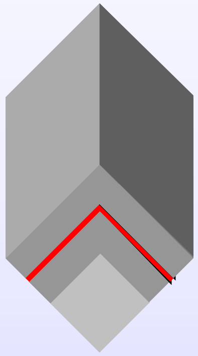




$G = \sigma_{1D} / L$

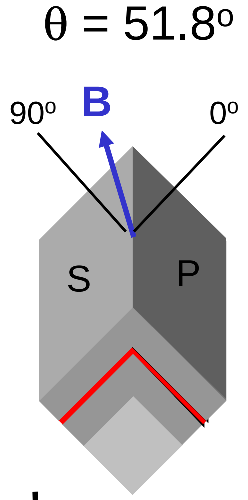
$\sigma_{1D} = \mathcal{N} l_0 \, e^2/h$

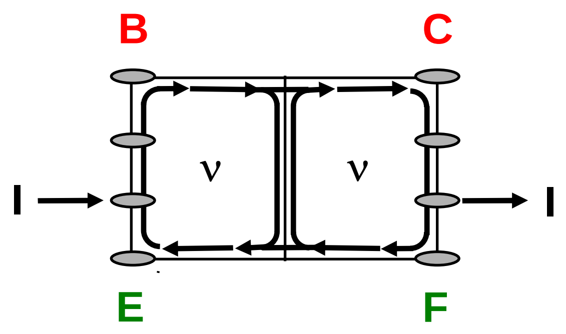
Characteristics Table

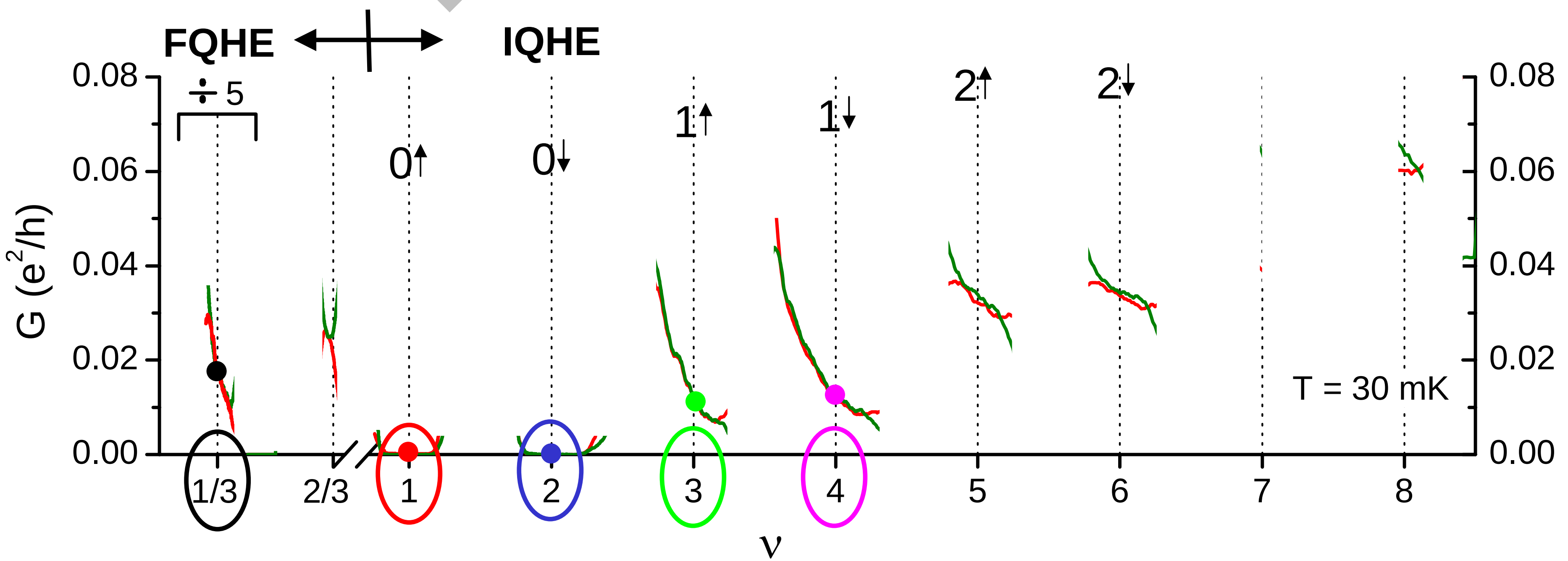


ν	*B*	conductance	length
1/3	20-23 T	conductor	--
1, 2	4-9 T	insulator	--
3, 4, 5, 6	0-2.5 T	conductor	1 / L

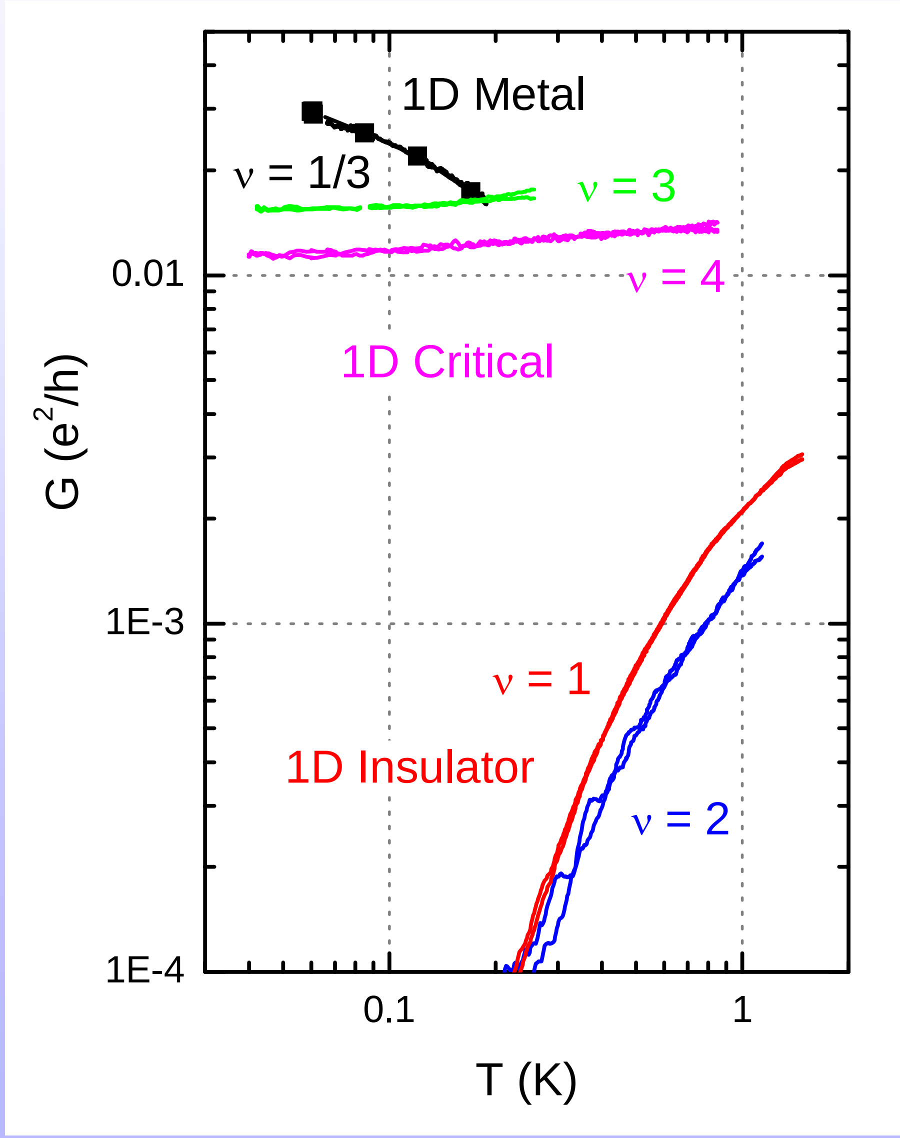
$\nu_s:\nu_p = 1:1$


θ = 51.8°
90°
B
0°
S
P


B
C
ν
ν
I
I
E
F

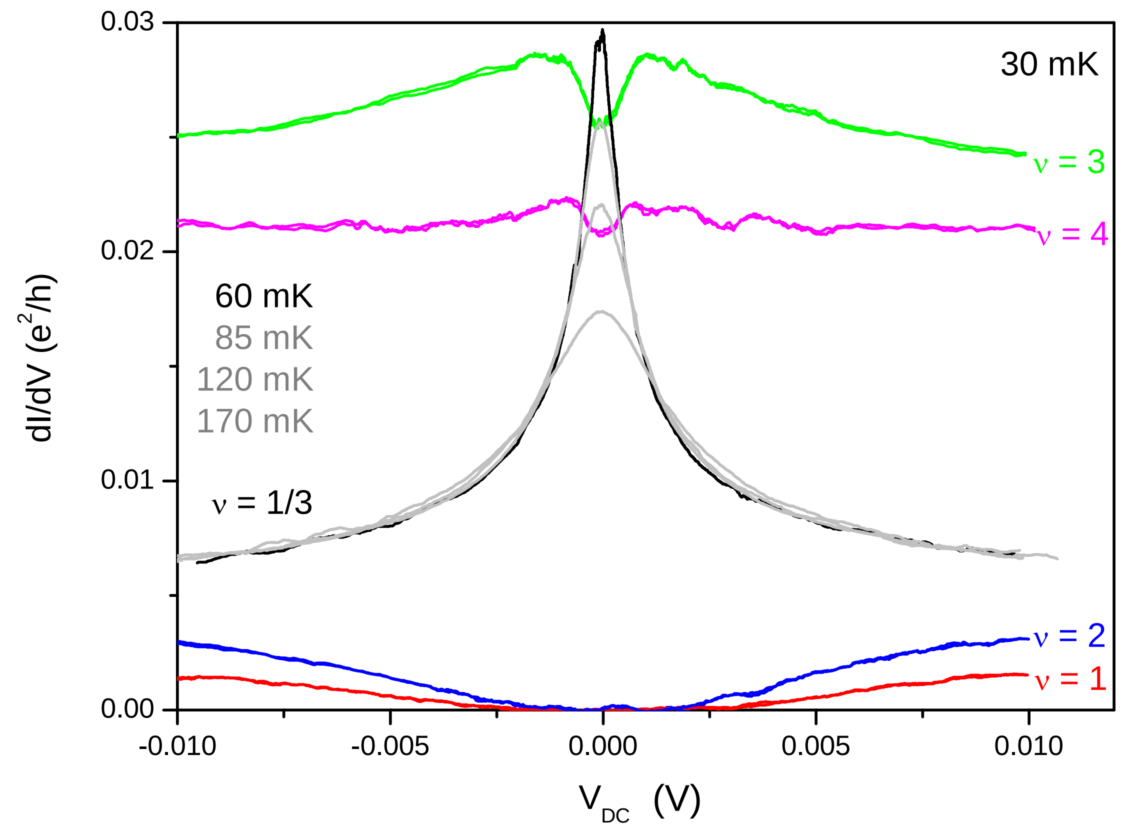

FQHE
IQHE
÷ 5
0↑
0↓
1↑
1↓
2↑
2↓
T = 30 mK
G (e²/h)
0.00
0.02
0.04
0.06
0.08
1/3
2/3
1
2
3
4
5
6
7
8
ν

Temperature dependence

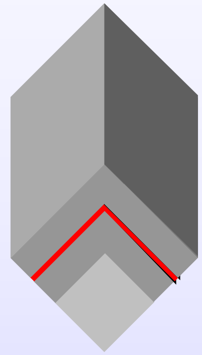


Character of 1D
Tuned by gap ν

Voltage dependence



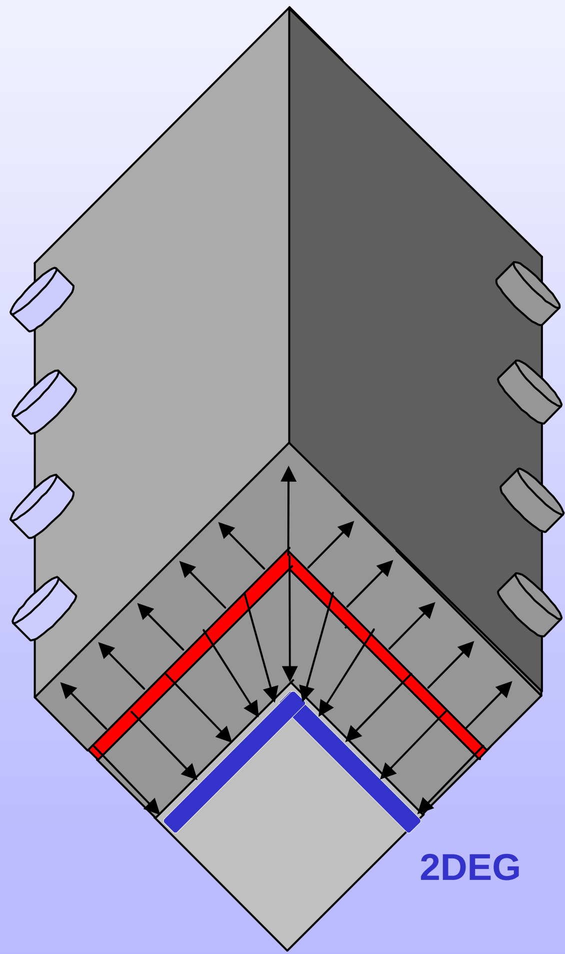
Characteristics Table



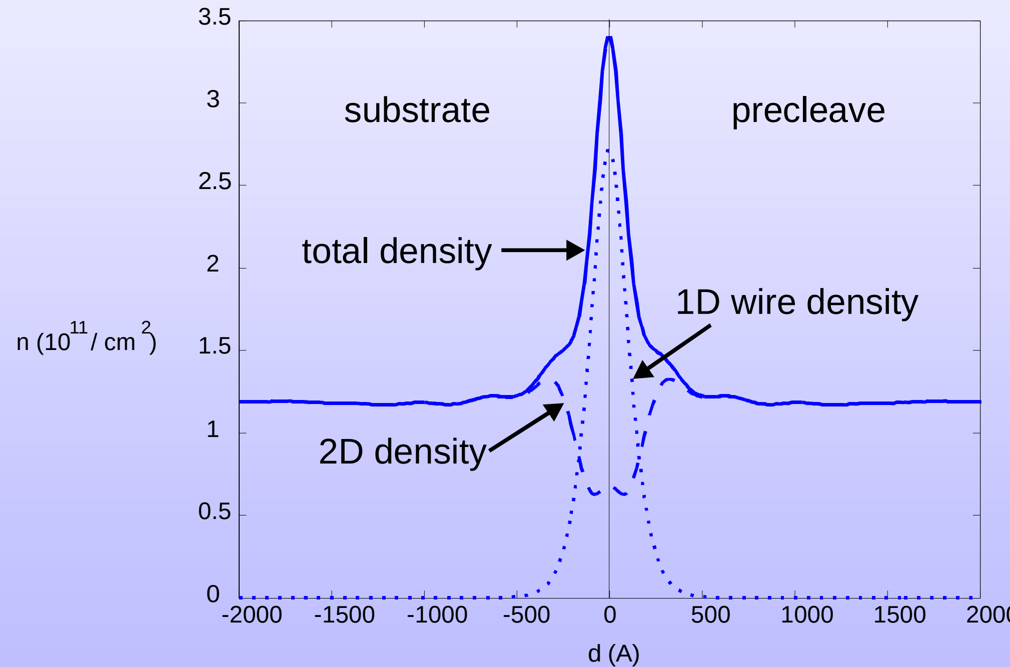
ν	B	conductance	length
1/3	20-23 T	metal	--
1, 2	4-9 T	insulator	--
3, 4, 5, 6	0-2.5 T	critical	1 / L

Hartree calculation

Hartree (B=0)



$$H = \frac{p^2}{2m^*} + V(x,z) + V_{e-e}$$

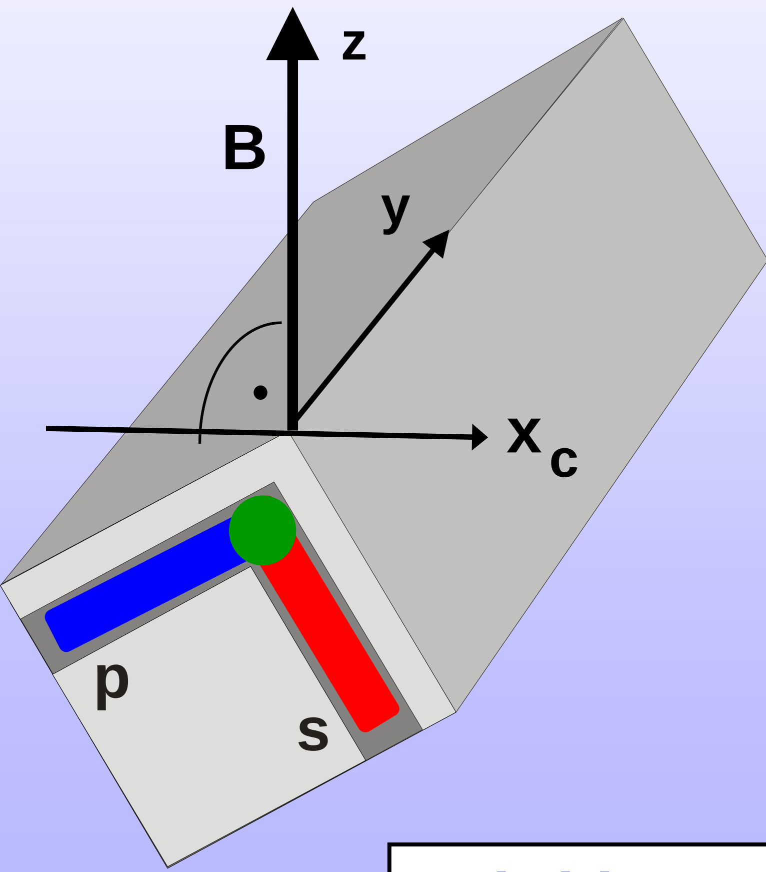


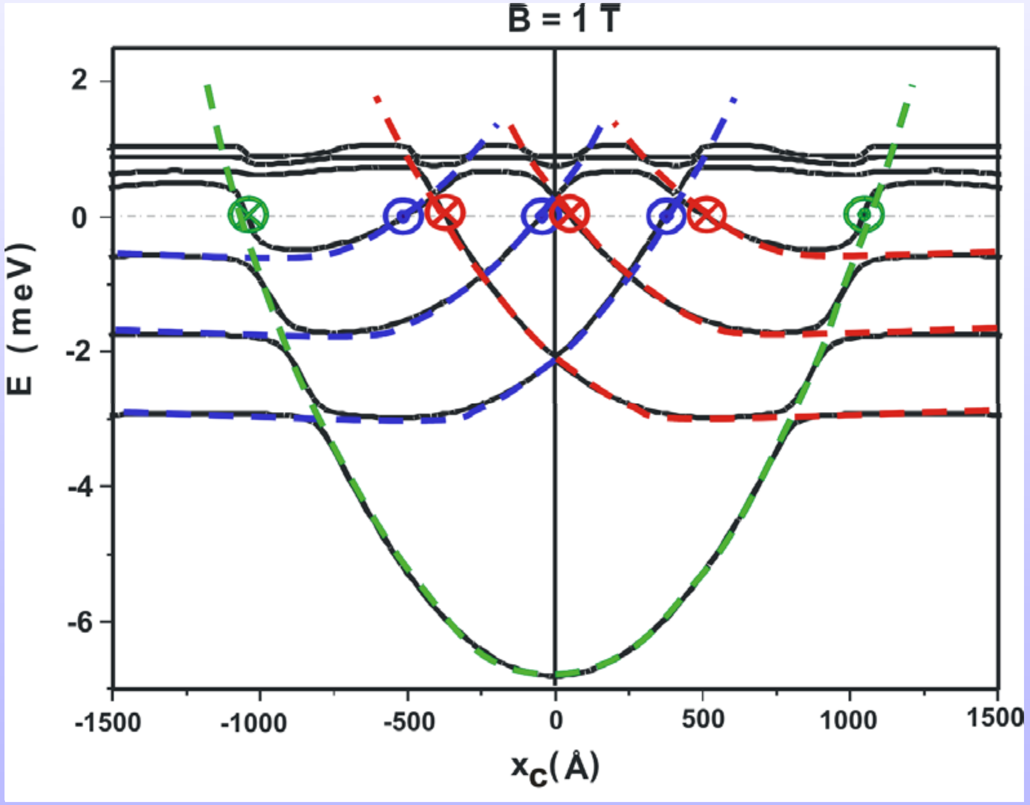
d = distance from corner

Landau Dispersion

Hartree with B-field

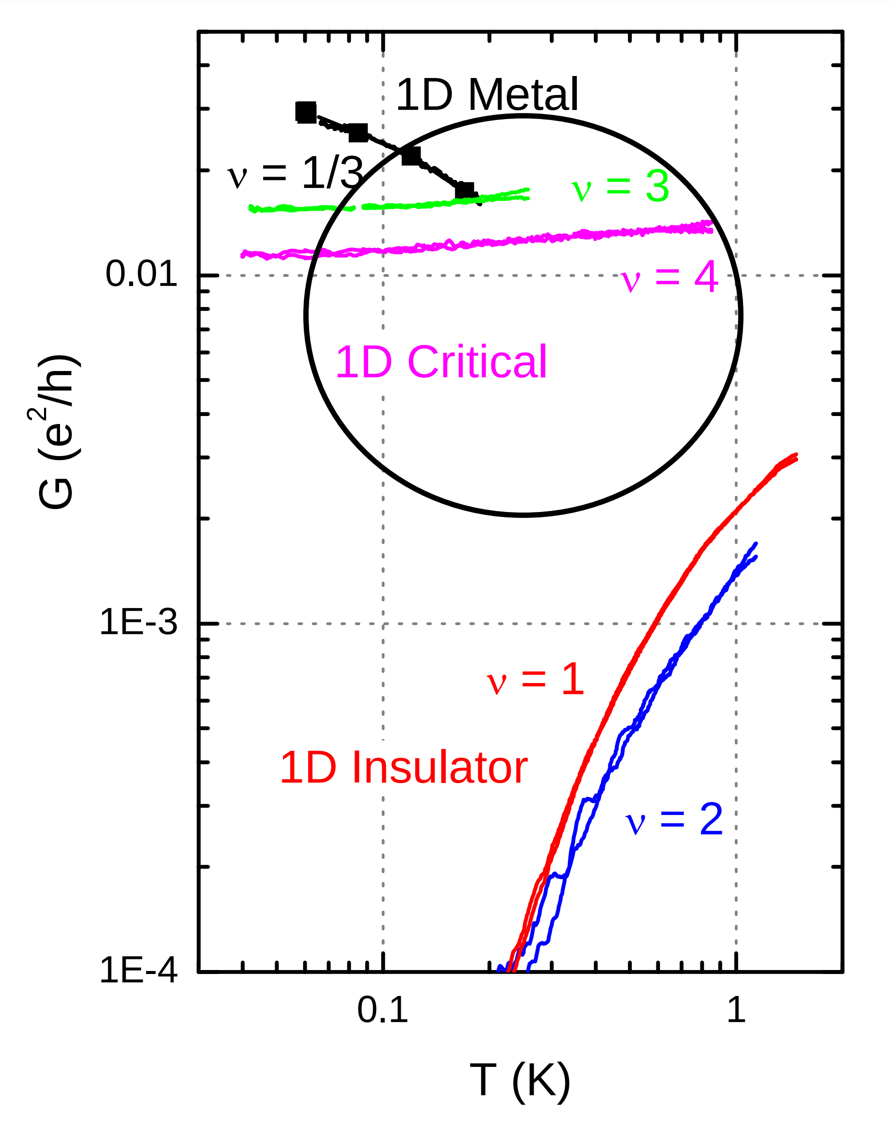
$$H = \frac{p^2}{2m^*} + V(x,z) + V_{e-e} + \frac{1}{2} m^* \omega_c^2 (x - x_0)^2$$





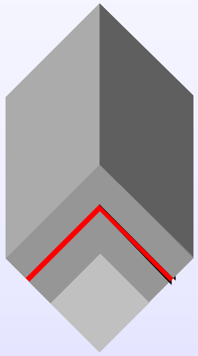
Hybrid 1D system

Temperature dependence



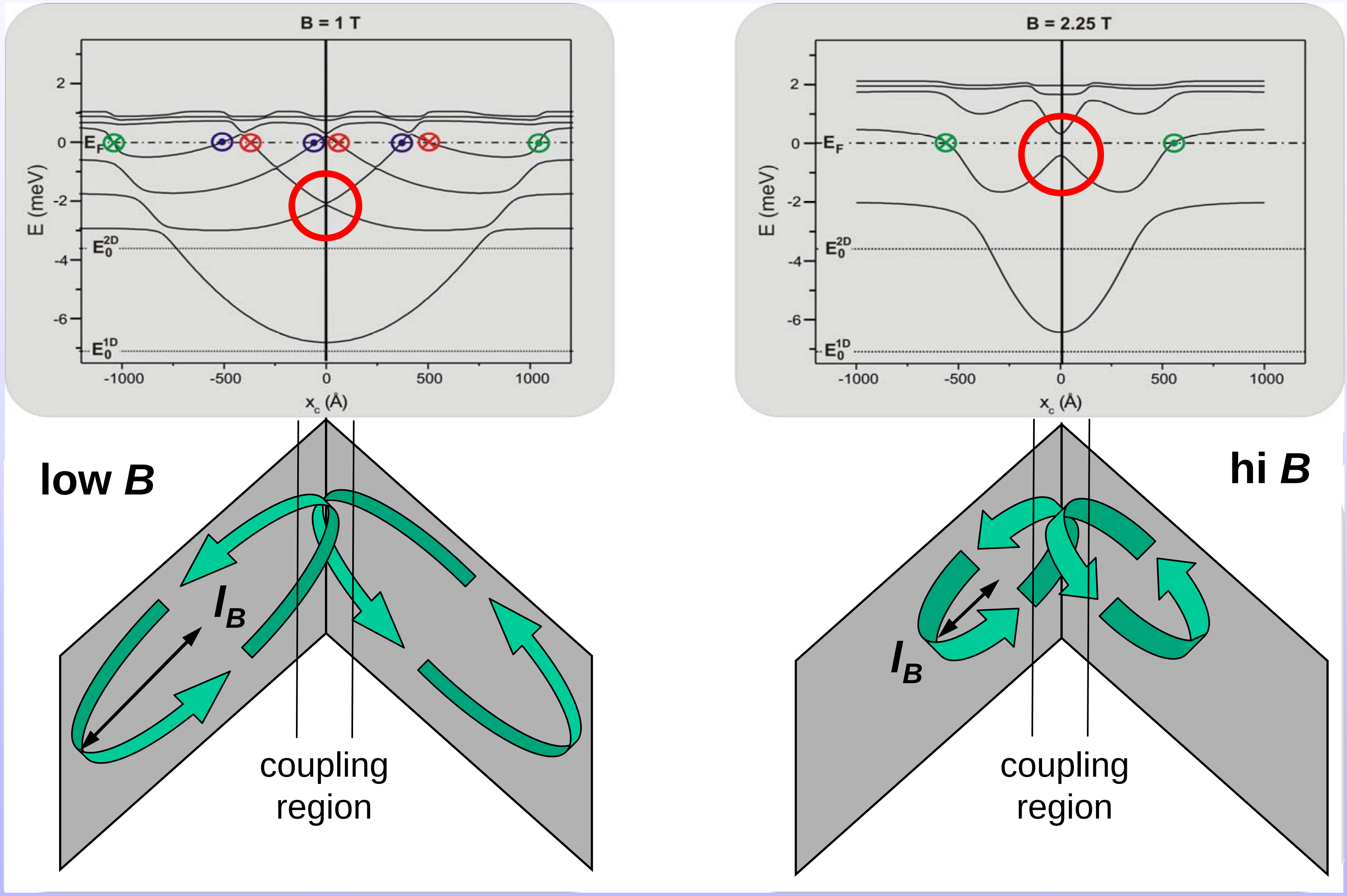
Multimode 1D wire

Characteristics Table



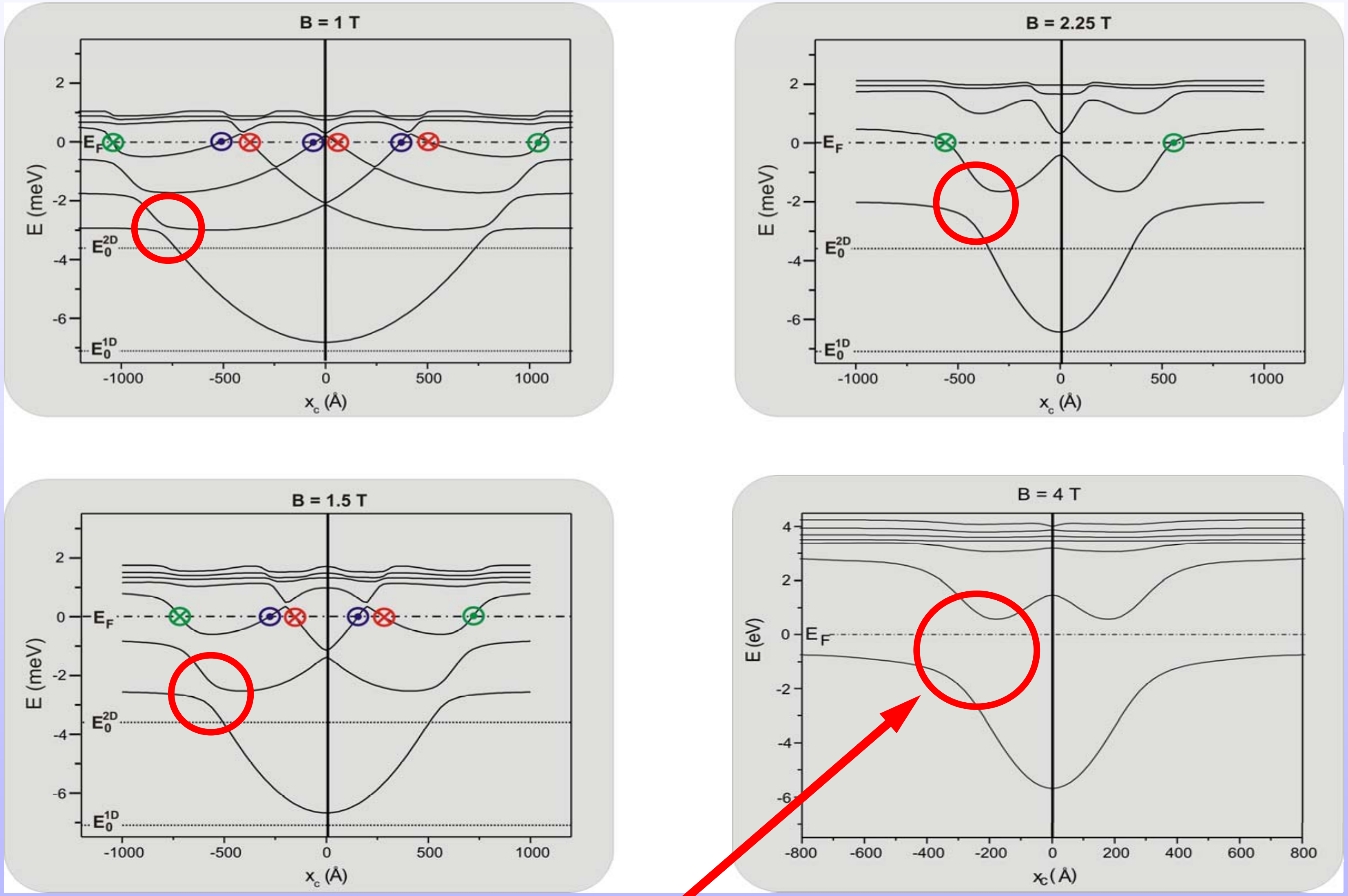
ν	*B*	conductance	length	model	interactions?
1/3	20-23 T	metal	--		
1, 2	4-9 T	insulator	--		
3, 4, 5, 6	0-2.5 T	critical	1 / L	multimode 1D wire	no

Dispersion at various B-fields



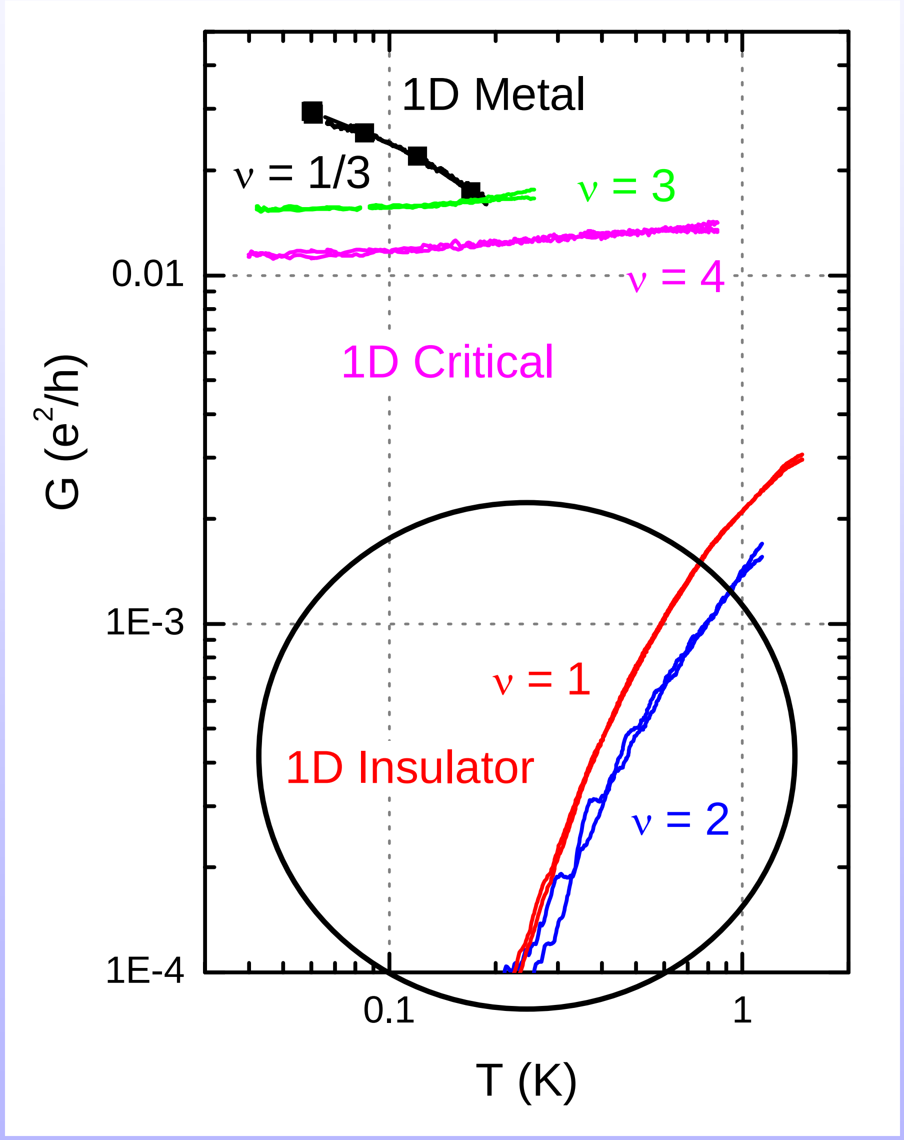
coupling ~ wavefunction overlap

Insulator at high B



coupling gap at high B => 1D Insulator

Temperature dependence



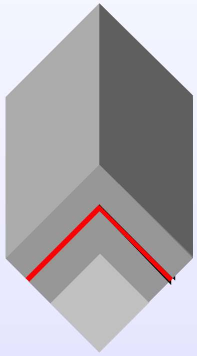
Anticrossing gap

OR

Localization in 1D

N.F. Mott and W.D. Twose (1961)
Abrahams, Anderson, Licciardello, Ramakrishnan (1979)

Characteristics Table



ν	*B*	conductance	length	model	interactions?
1/3	20-23 T	metal	--		
1, 2	4-9 T	insulator	--	level anticrossing localization	no no
3, 4, 5, 6	0-2.5 T	critical	1 / L	multimode 1D wire	no

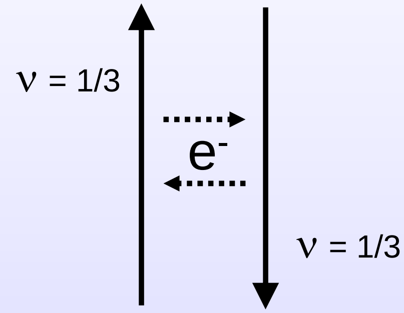
1D Metal, ν = 1/3

Metal = e- tunnel coupled LL´s

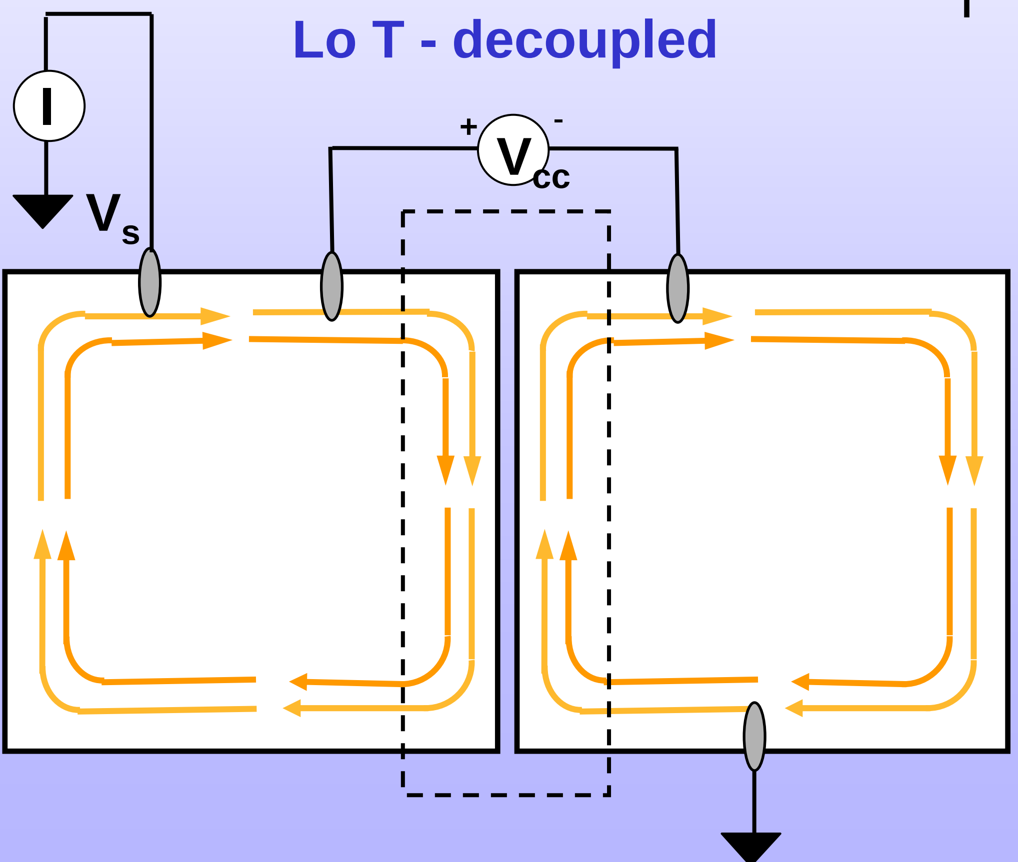
S. Renn, D. Arovas,
PRB 51, 16832 (1995)

C. Kane, M. Fisher,
PRB 56, 15231 (1996)

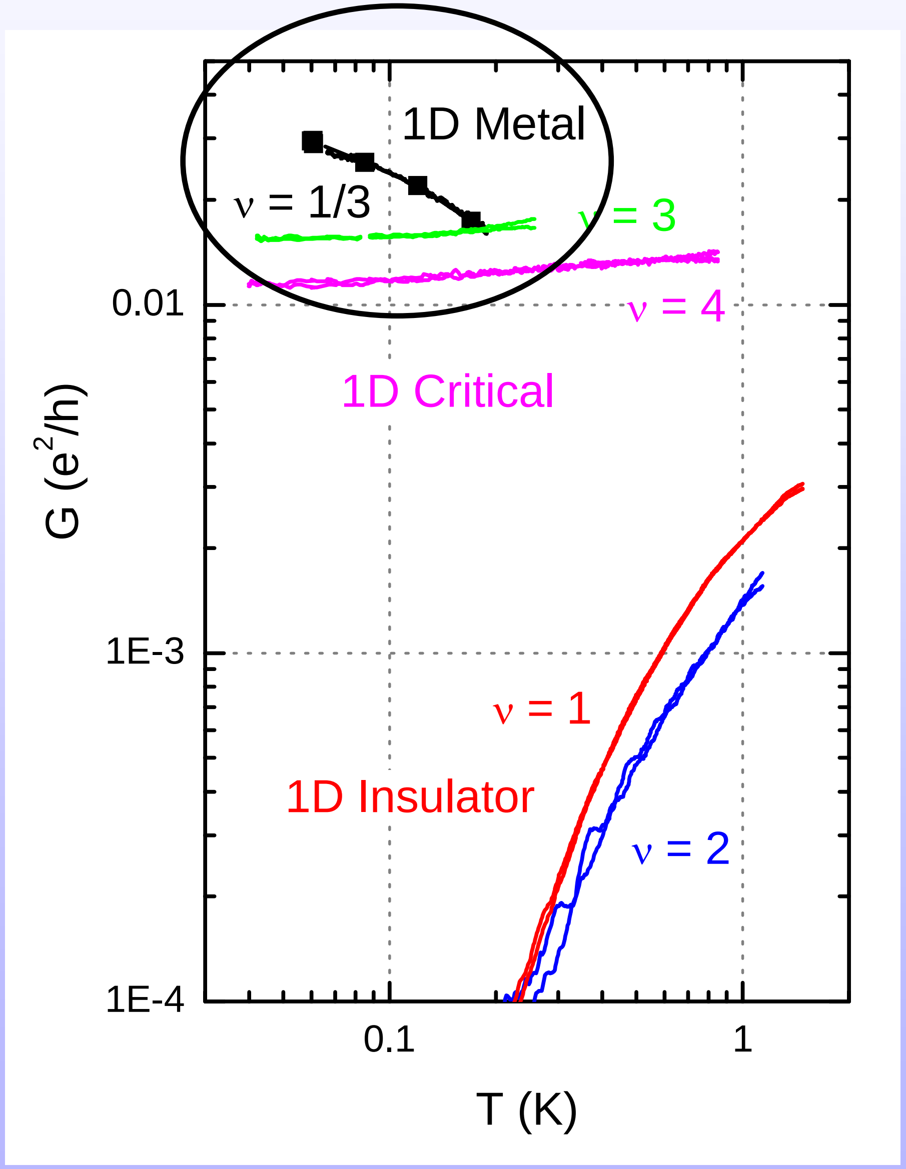
T. Giamarchi and H. J.Schulz
PRB 37, 325 (1988)



Lo T - decoupled

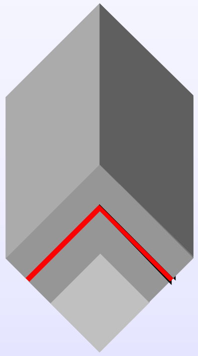


Temperature dependence



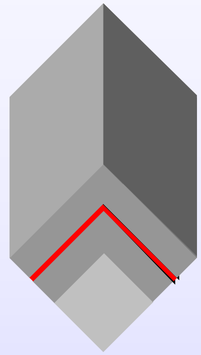
Antiwire of chiral Luttinger liquids with e- tunneling

Characteristics Table



ν	*B*	conductance	length	model	interactions?
1/3	20-23 T	metal	--	LL antiwire	YES
1, 2	4-9 T	insulator	--	level anticrossing localization	no no
3, 4, 5, 6	0-2.5 T	critical	1 / L	multimode 1D wire	no

Conclusions

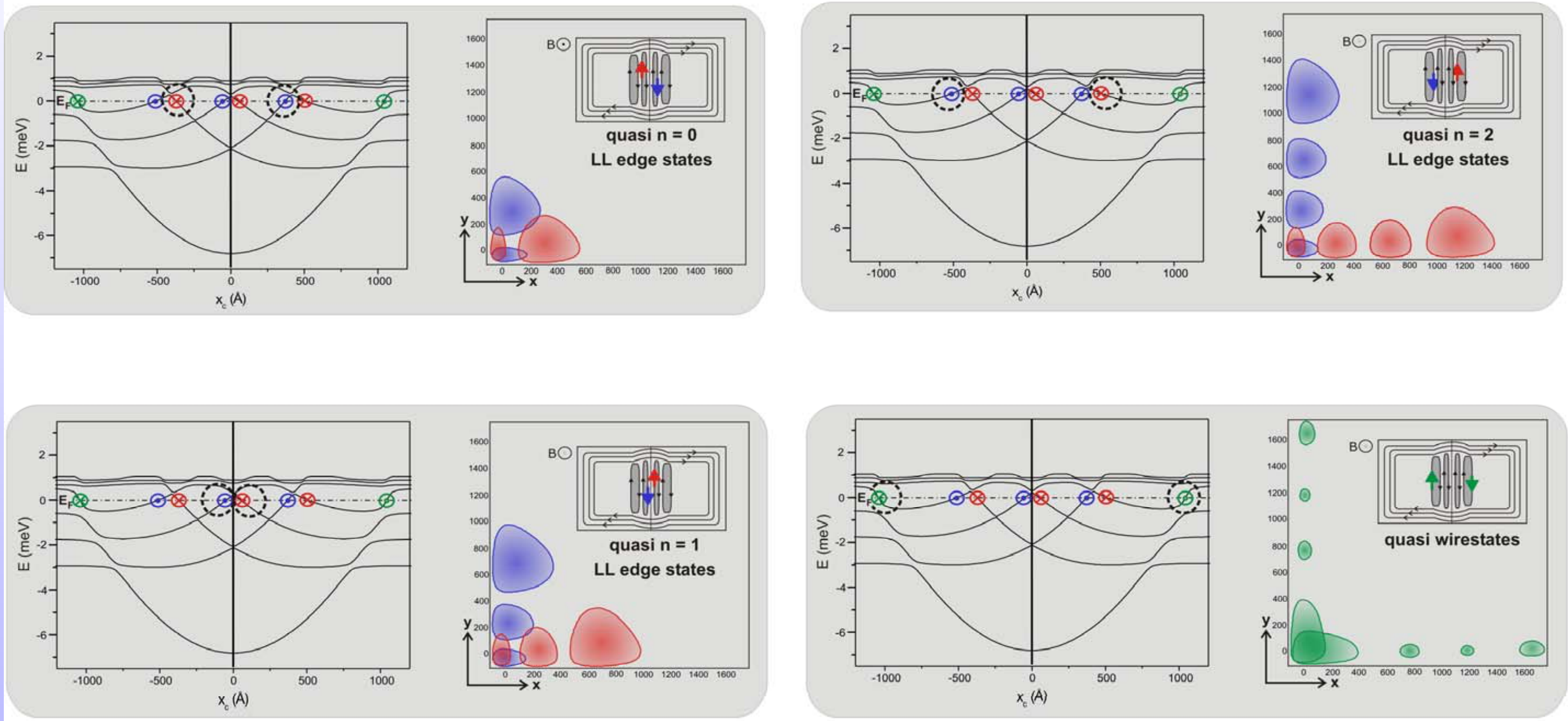


* Demonstrate 1D system bound at corner of bent QHE
* Measure conductance as function of ν
* Measure mean free path l_0
* Tune 1D metal – critical – insulator behavior with ν
* Metallic state:

  Evidence of 1D metal

Wavefunctions

B = 1 T



Strong overlap of counter-propagating channels