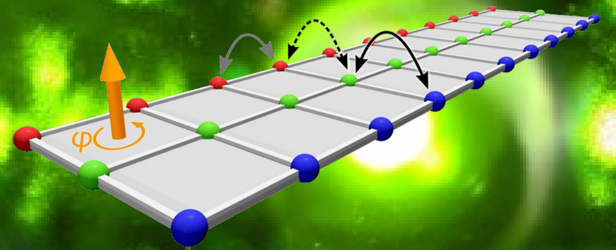
Michele Filippone



Theory
S. Greschner, **MF**, T. Giamarchi **PRL** (2019)
MF, C.-E. Bardyn, S. Greschner, T. Giamarchi **PRL** (2019)

arXiv:2205.13567
to appear in ***SCIENCE***

Observation of the Universal Hall Response of Strongly Interacting Fermions

EXPERIMENTAL TEAM

Daniele Tusi

Lorenzo Franchi

Jacopo Parravicini

Leonardo Fallani

Jacopo Catani

Giacomo Cappellini

Lorenzo Livi

Tianwei Zhou

lens
European Laboratory for Non-Linear Spectroscopy

UNIVERSITÀ DEGLI STUDI FIRENZE

THEORY

Charles-Edouard Bardyn

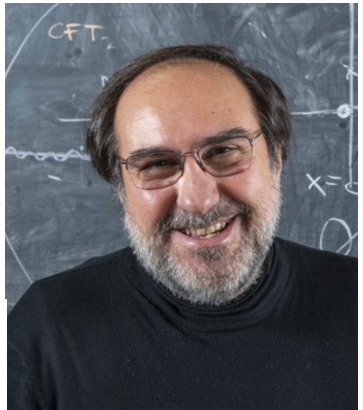
UNIVERSITÉ DE GENÈVE

Cécile Repellin

LPMMC

Sebastian Greschner

UNIVERSITÉ DE GENÈVE

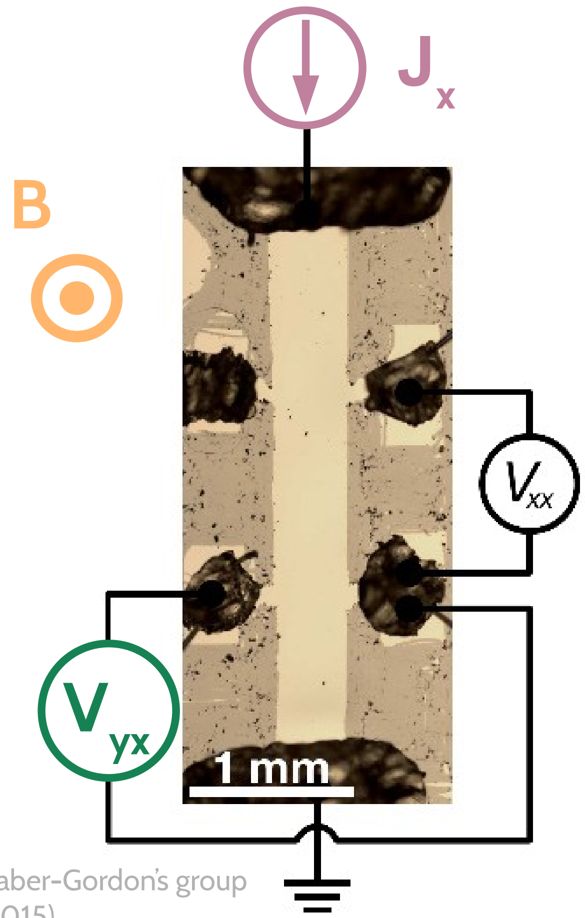


Thierry Giamarchi

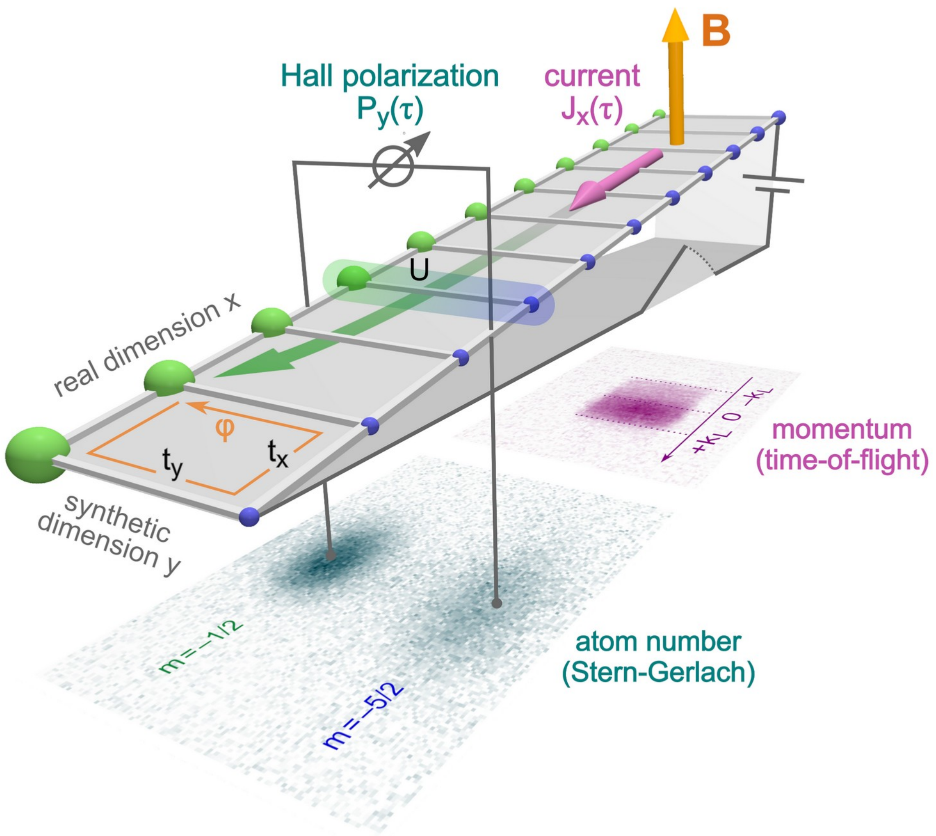
UNIVERSITÉ DE GENÈVE

Quantum simulation of a Hall experiment

SOLID STATE



Goldhaber-Gordon's group
PRL (2015)



ULTRACOLD ATOMS

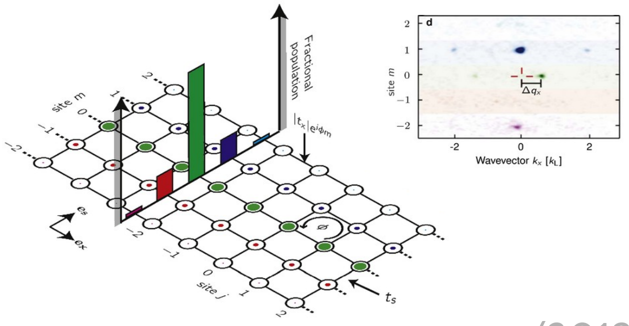
First observation of universal many-body effects

Quantum simulation with ultracold atoms

Bosons
weakly interacting

Imaging topology of Hofstadter ribbons

Dina Genkina[1], Lauren M Aycock[1], Hsin-I Lu[1,2], Mingwu Lu[1], Alina M Pineiro[1] and I B Spielman[1]

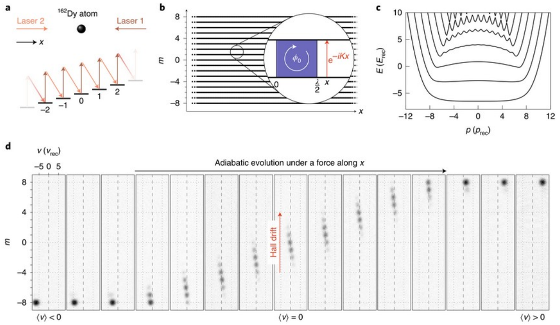


(2019)

nature physics
LETTERS
https://doi.org/10.1038/s41567-020-0942-5
Check for updates

Probing chiral edge dynamics and bulk topology of a synthetic Hall system

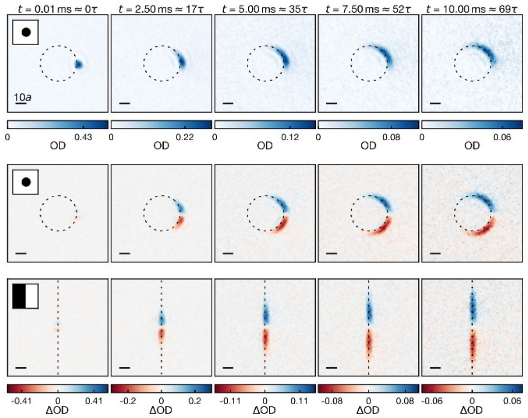
Thomas Chalopin[1,3], Tanish Satoor[1,3], Alexandre Evrard[1], Vasiliy Makhalov[1,2], Jean Dalibard[1], Raphael Lopes[1] and Sylvain Nascimbene[1]✉



(2020)

Real-space detection and manipulation of topological edge modes with ultracold atoms

Christoph Braun[1,2,3,*], Raphaël Saint-Jalm[1,2,3,*], Alexander Hesse[1,2,3], Johannes Arceri[1,2,3], Immanuel Bloch[1,2,3], Monika Aidelsburger[1,2†]



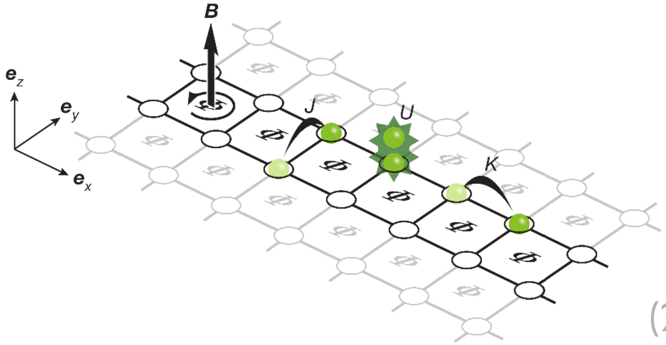
(2023)

Bosons (again)
few-body correlations

LETTER
doi:10.1038/nature22811

Microscopy of the interacting Harper–Hofstadter model in the two-body limit

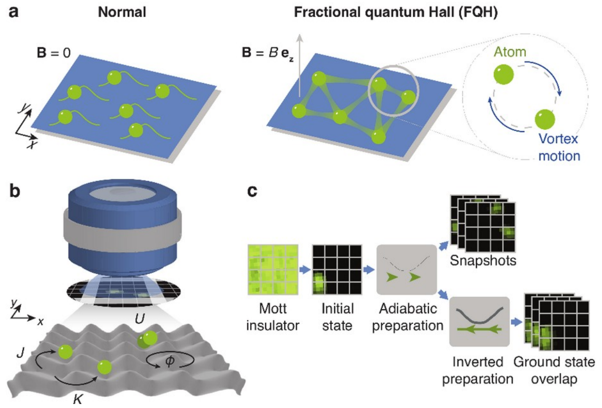
M. Eric Tai[1], Alexander Lukin[1], Matthew Rispoli[1], Robert Schittko[1], Tim Menke[1], Dan Borgnia[1], Philipp M. Preiss[1]†, Fabian Grusdt[1], Adam M. Kaufman[1] & Markus Greiner[1]



(2017)

Realization of a fractional quantum Hall state with ultracold atoms

Julian Léonard,[1,*] Sooshin Kim,[1] Joyce Kwan,[1] Perrin Segura,[1] Fabian Grusdt,[2,3] Cécile Repellin,[4] Nathan Goldman,[5] and Markus Greiner[1]

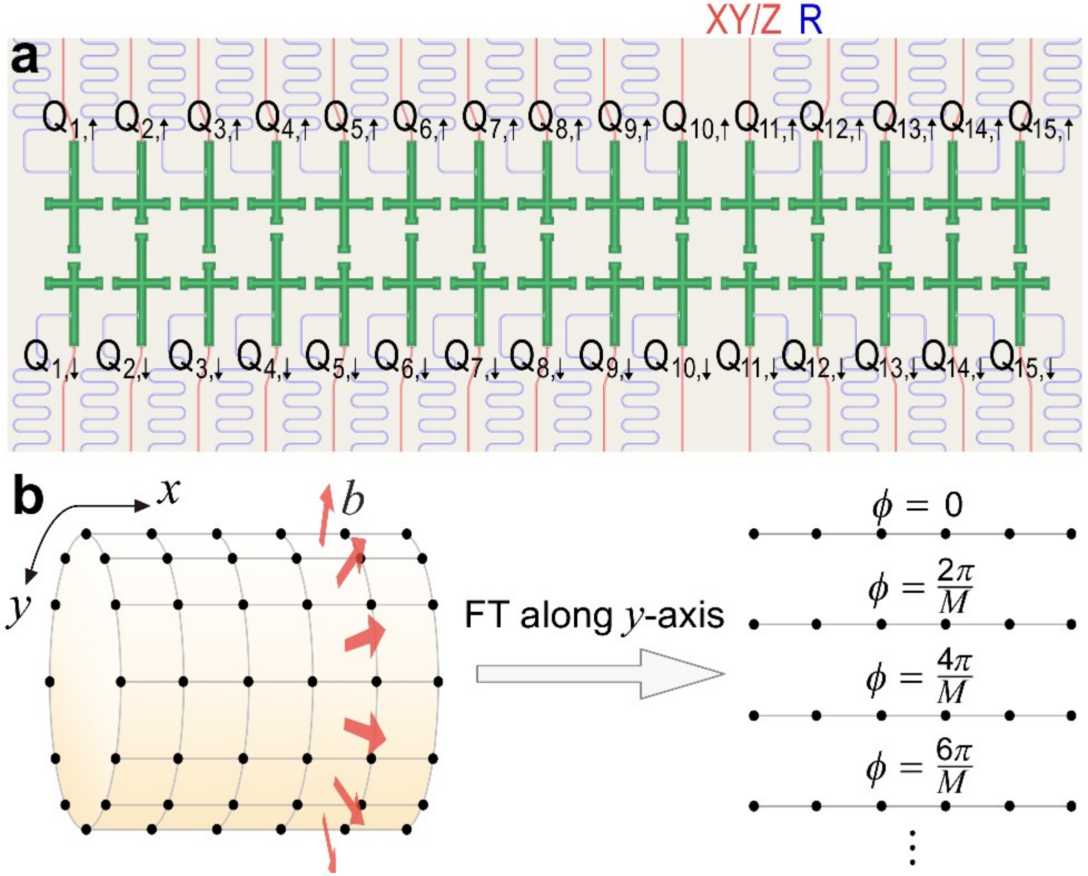


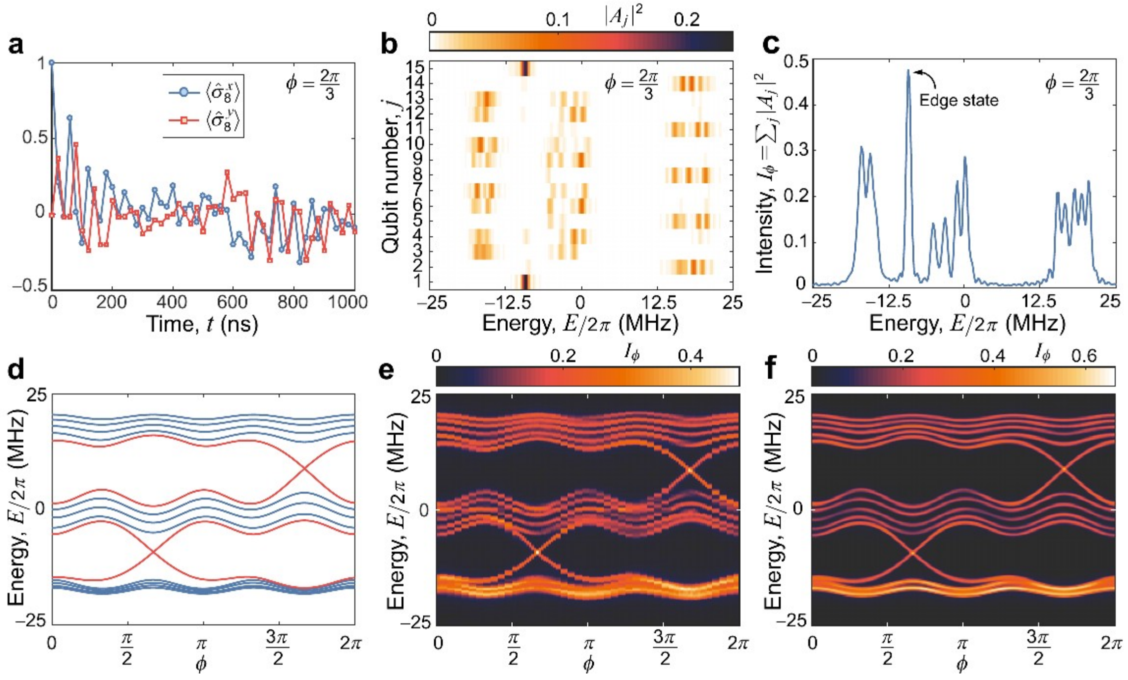
(2022)

Simulating quantum Hall effects on a superconducting quantum processor

Zhong-Cheng Xiang,[1,*] Kaixuan Huang,[1,6,5,*] Yu-Ran Zhang,[2,3,*] Tao Liu,[4] Yun-Hao Shi,[1] Cheng-Lin Deng,[1] Tong Liu,[1] Hao Li,[1] Gui-Han Liang,[1] Zheng-Yang Mei,[1] Haifeng Yu,[5] Guangming Xue,[5] Ye Tian,[1] Xiaohui Song,[1] Zhi-Bo Liu,[6] Kai Xu,[1,5,7,8,†] Dongning Zheng,[1,7,8] Franco Nori,[2,3,9,‡] and Heng Fan[1,5,7,8,§]

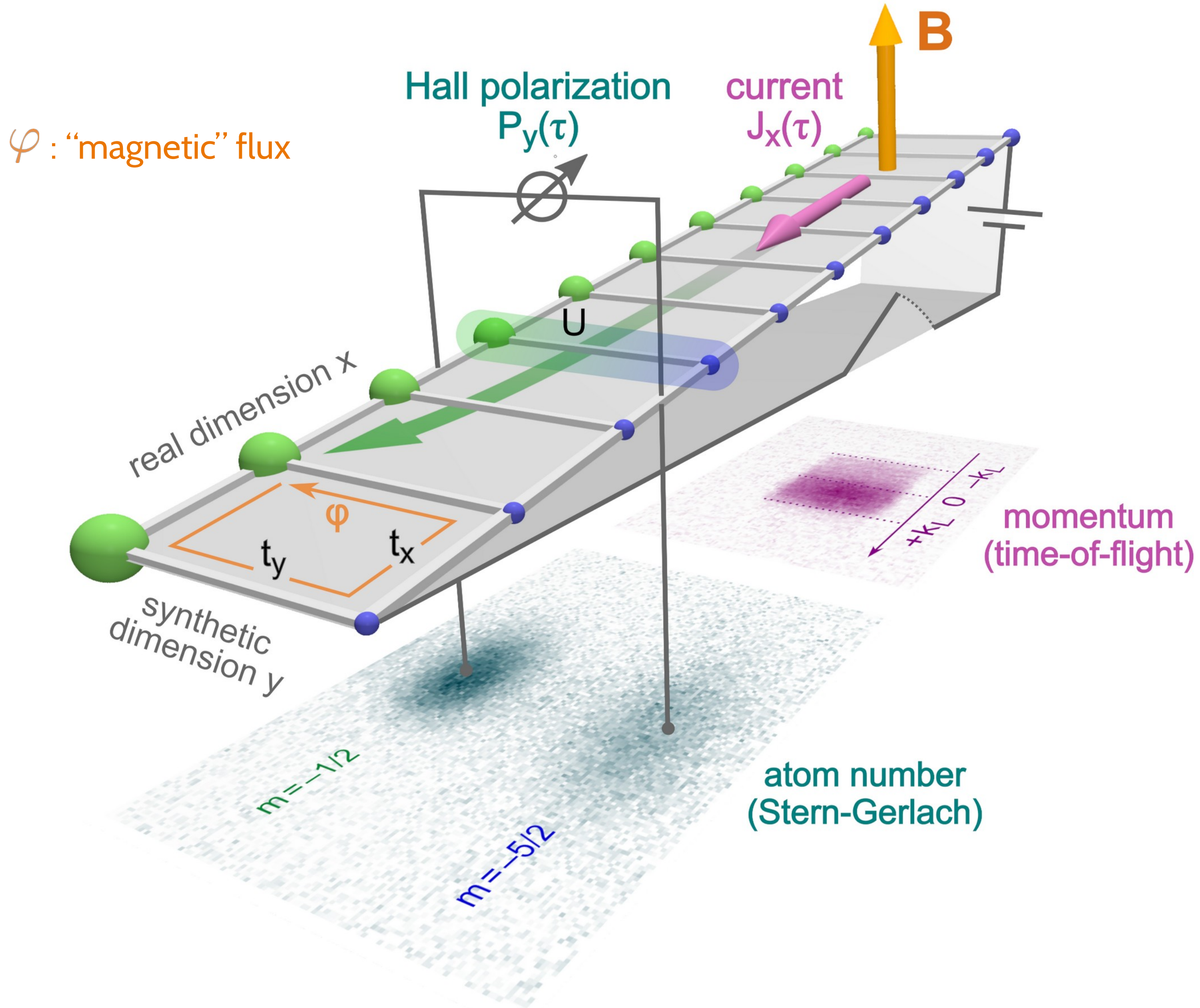
arXiv:2207.11797v1





Quantum simulation of **many-body** effects with fermions

Probing the Hall response of a 2-leg fermion ladder



Simulation of Harper-Hoftsadter model

$$H = -\,t_x \sum_{j,m} \left[a^\dagger_{j,m} a_{j+1,m} + \text{h.c.}\right] \quad \text{longitudinal hopping}$$

$$-\,t_y \sum_j \left[e^{i\varphi j} a^\dagger_{j,1} a_{j,2} + \text{h.c.}\right] + U \sum_j n_{j,1} n_{j,2}$$

transverse hopping — interactions

"***Hall Imbalance***" a proxy of the Hall resistance

$$\Delta_{\mathrm{H}} = \frac{P_y}{J_x}$$

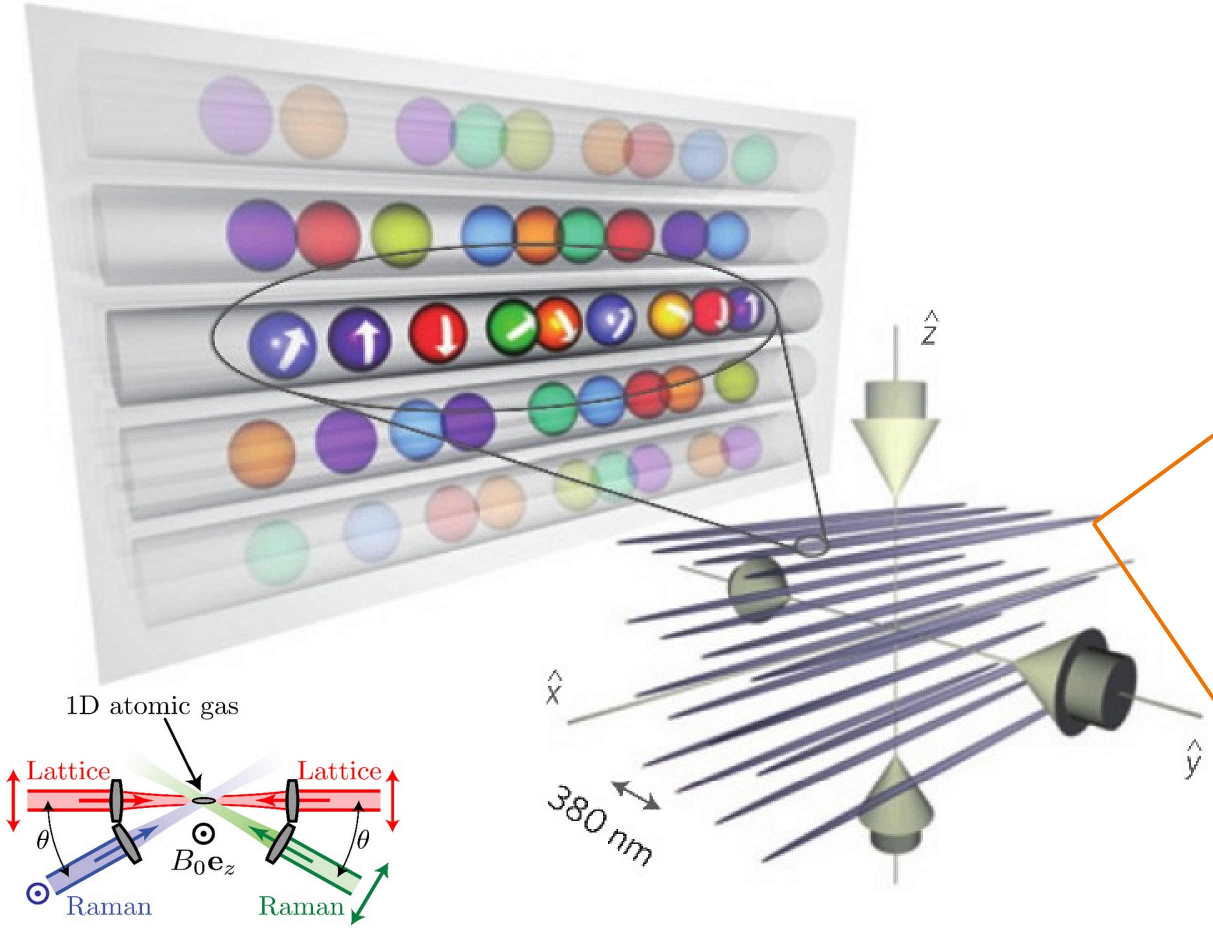
MF, C.-E.Bardyn, T. Giamarchi PRB (2018) – S. Greschner, **MF**, T. Giamarchi PRL (2019)
MF, C.-E. Bardyn, S. Greschner, T. Giamarchi PRL (2019)

Synthesizing artificial gauge fields with ^{173}Yb (fermions)

LETTERS | nature physics
PUBLISHED ONLINE: 2 FEBRUARY 2014 | DOI: 10.1038/NPHYS2878

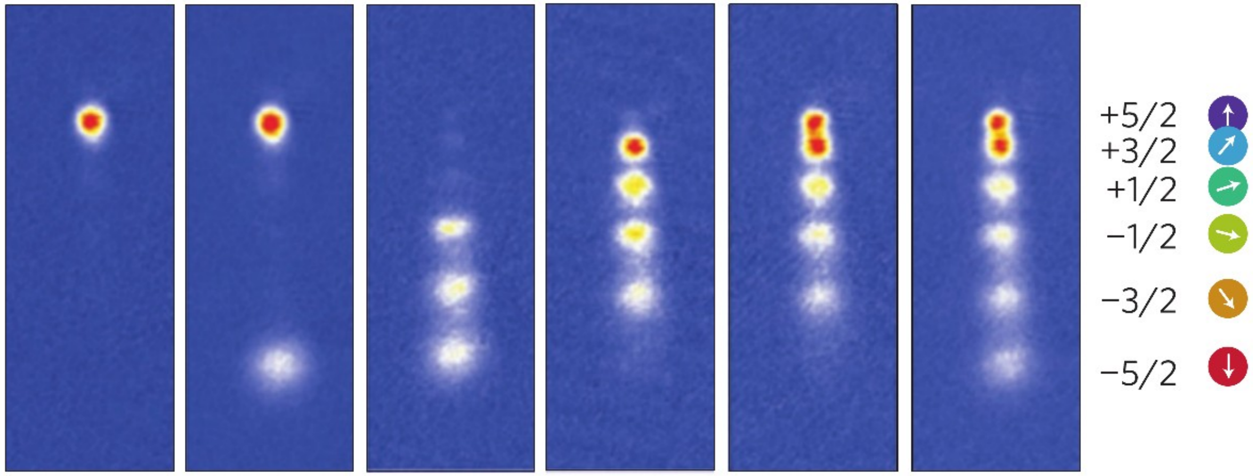
A one-dimensional liquid of fermions with tunable spin (2014)

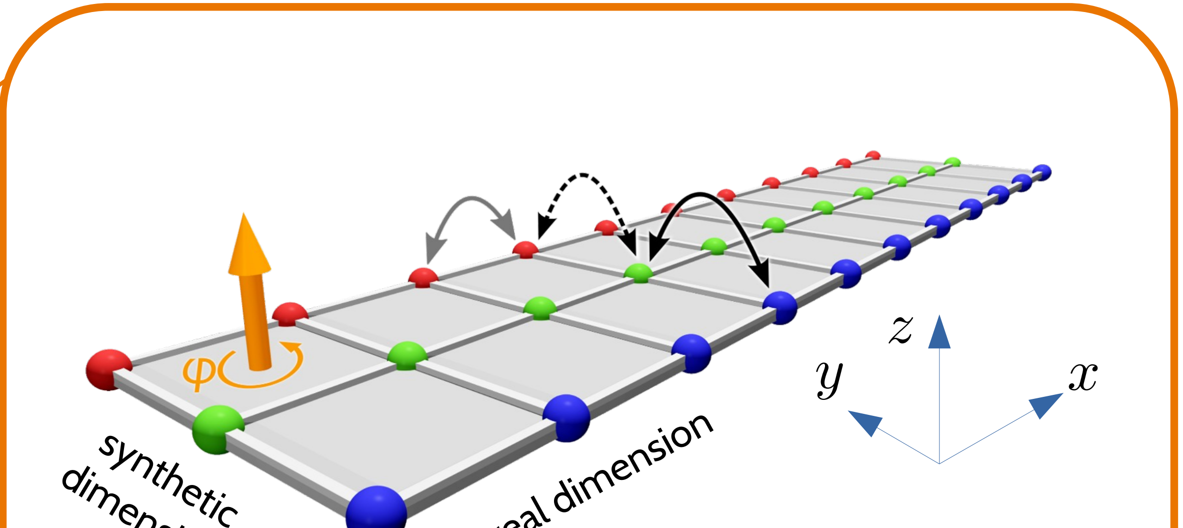
Guido Pagano[1,2], Marco Mancini[1,3], Giacomo Cappellini[1], Pietro Lombardi[1,3], Florian Schäfer[1], Hui Hu[4], Xia-Ji Liu[4], Jacopo Catani[1,5], Carlo Sias[1,5], Massimo Inguscio[1,3,5] and Leonardo Fallani[1,3,5*]



Jaksch and Zoller **New J. Phys.** (2003), Celi *et al.* **PRL** (2014)

Stern-Gerlach measurement of the spin



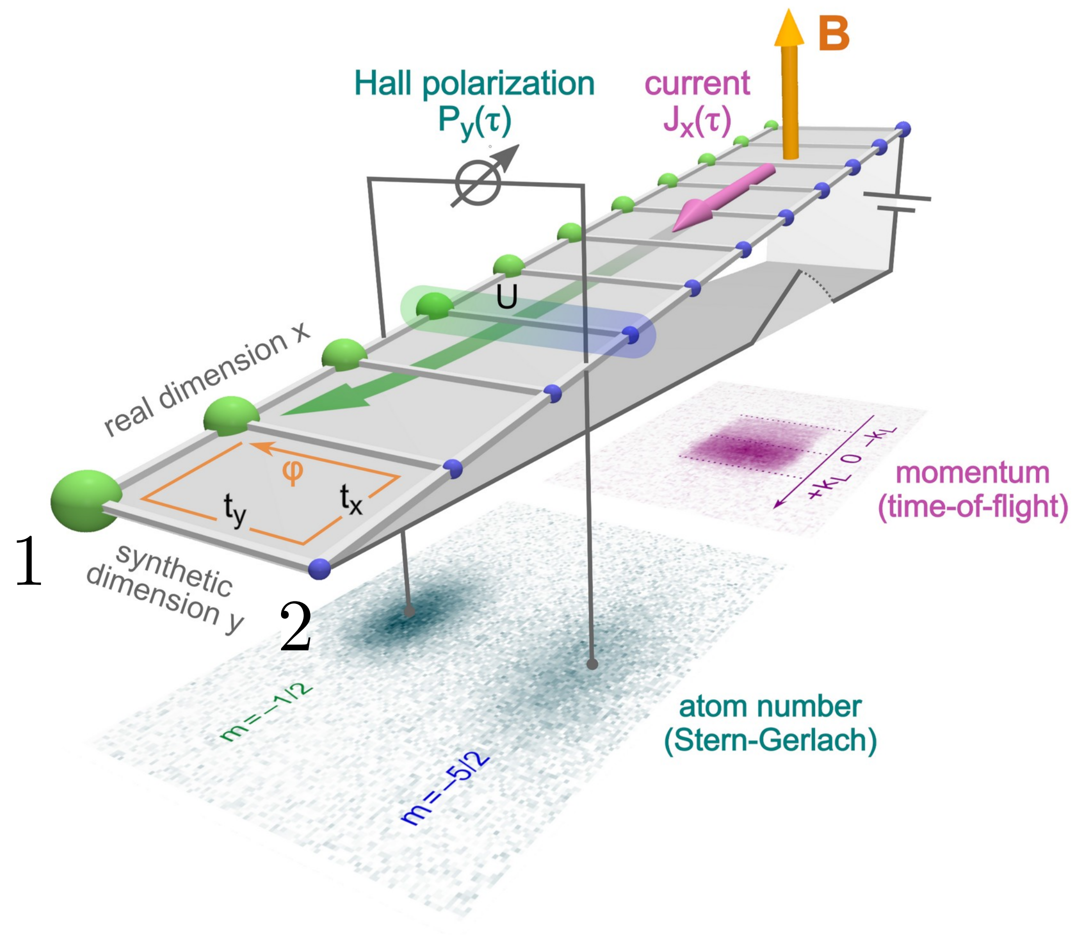


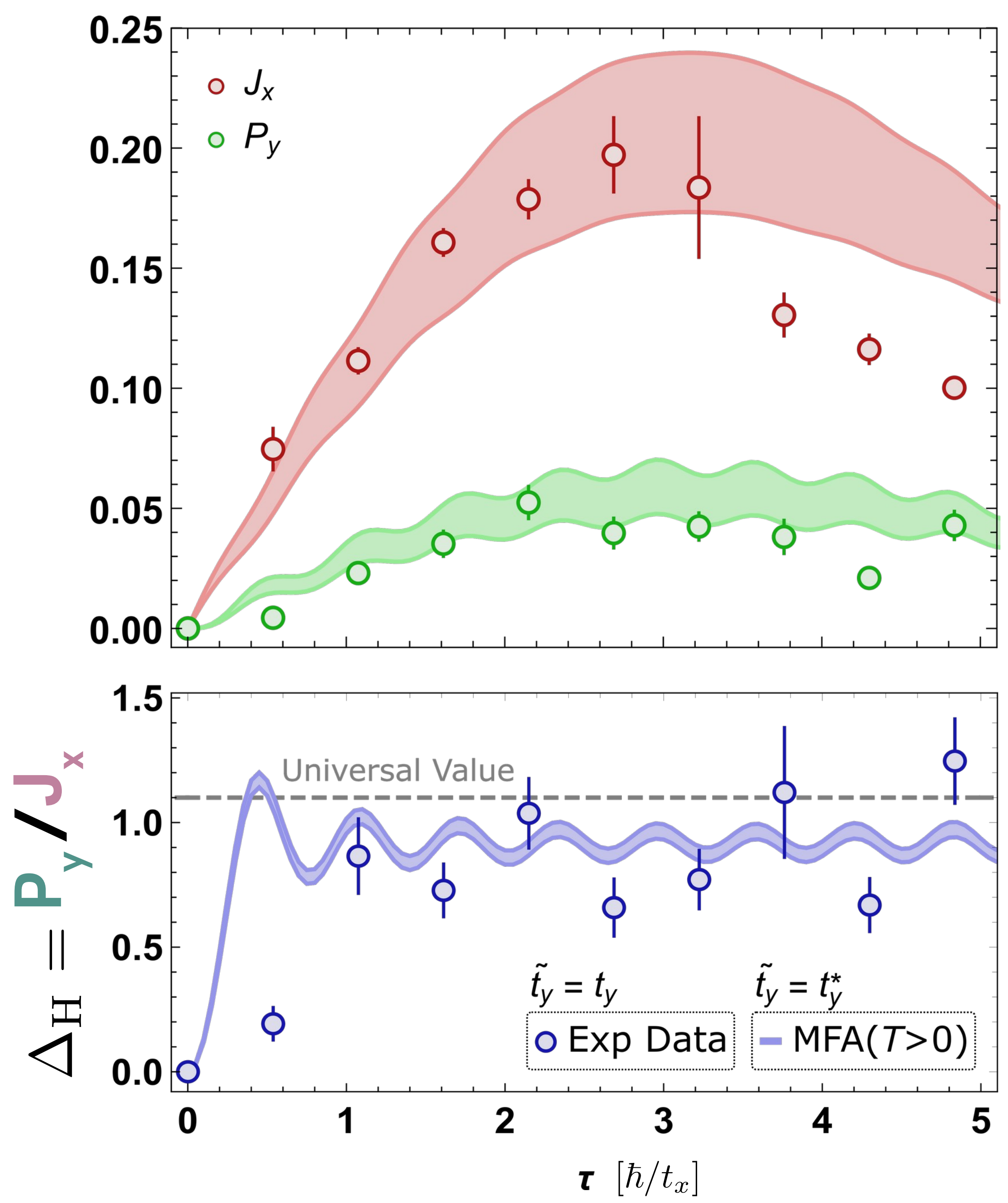
Pagano *et al.* **Science.** (2015)
Stuhl *et al.* **Science** (2015)

how it looks like

Measuring the Hall response

After-quench real time evolution





Polarization

$$P_y = \frac{N_{-1/2}(\tau) - N_{-5/2}(\tau)}{N_{-1/2}(\tau) + N_{-5/2}(\tau)}$$

Current

$$J_x(\tau) = \int_{-1}^{1} \sin(\pi k) n(k,\tau)\, dk$$

Measuring the Hall response

After-quench real time evolution

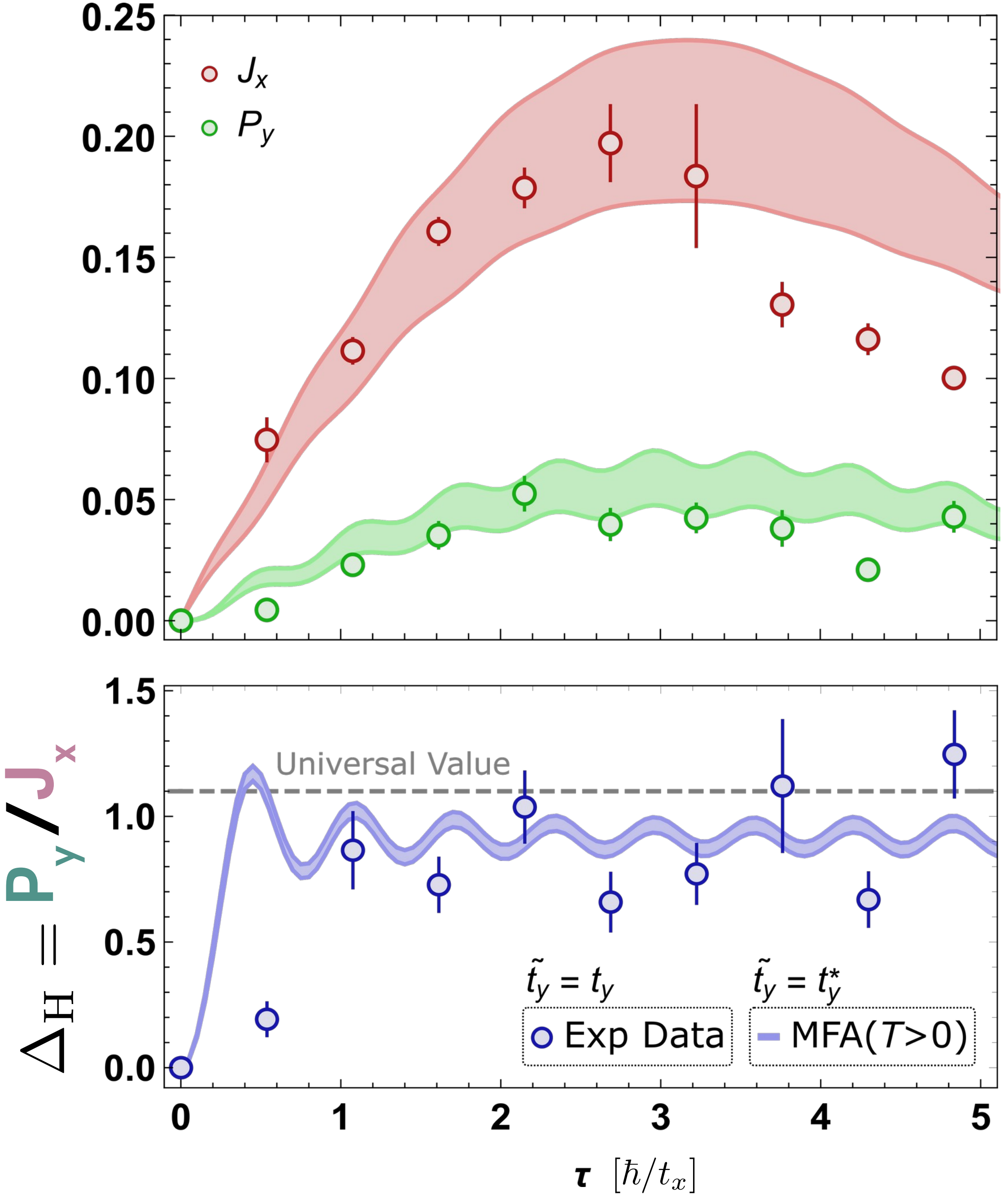
Hall imbalance

$$\Delta_{\mathrm{H}} = \frac{P_y}{J_x}$$

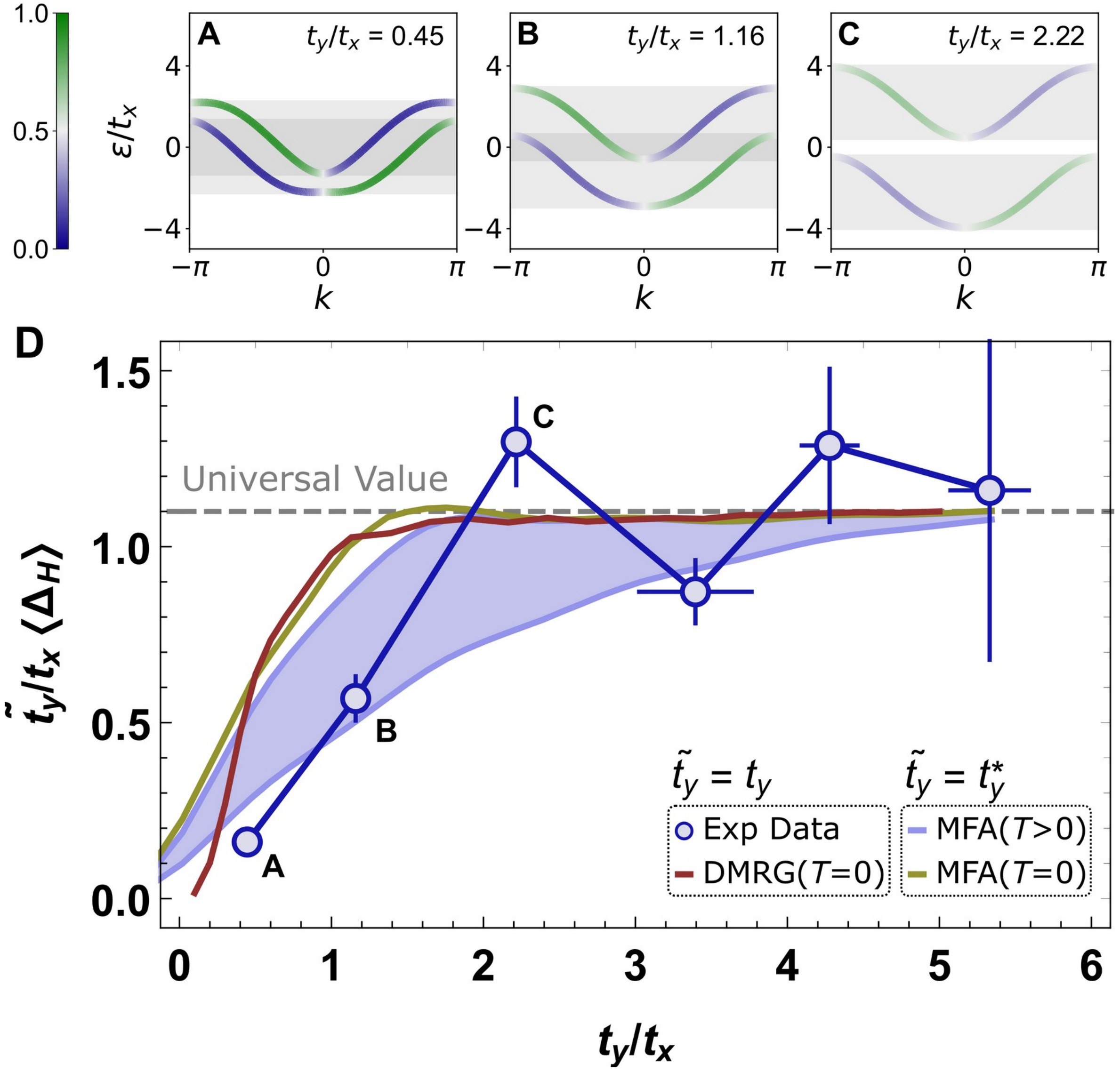
Time-averaged Hall imbalance

$$\langle \Delta_{\mathrm{H}} \rangle = \frac{1}{T}\int_0^T d\tau \Delta_{\mathrm{H}}(\tau)$$

Averaging time $T = 5\hbar/t_x$



Transverse tunneling – t_y – dependence



Non-interacting
2-band spectrum

"Universal" Hall imbalance

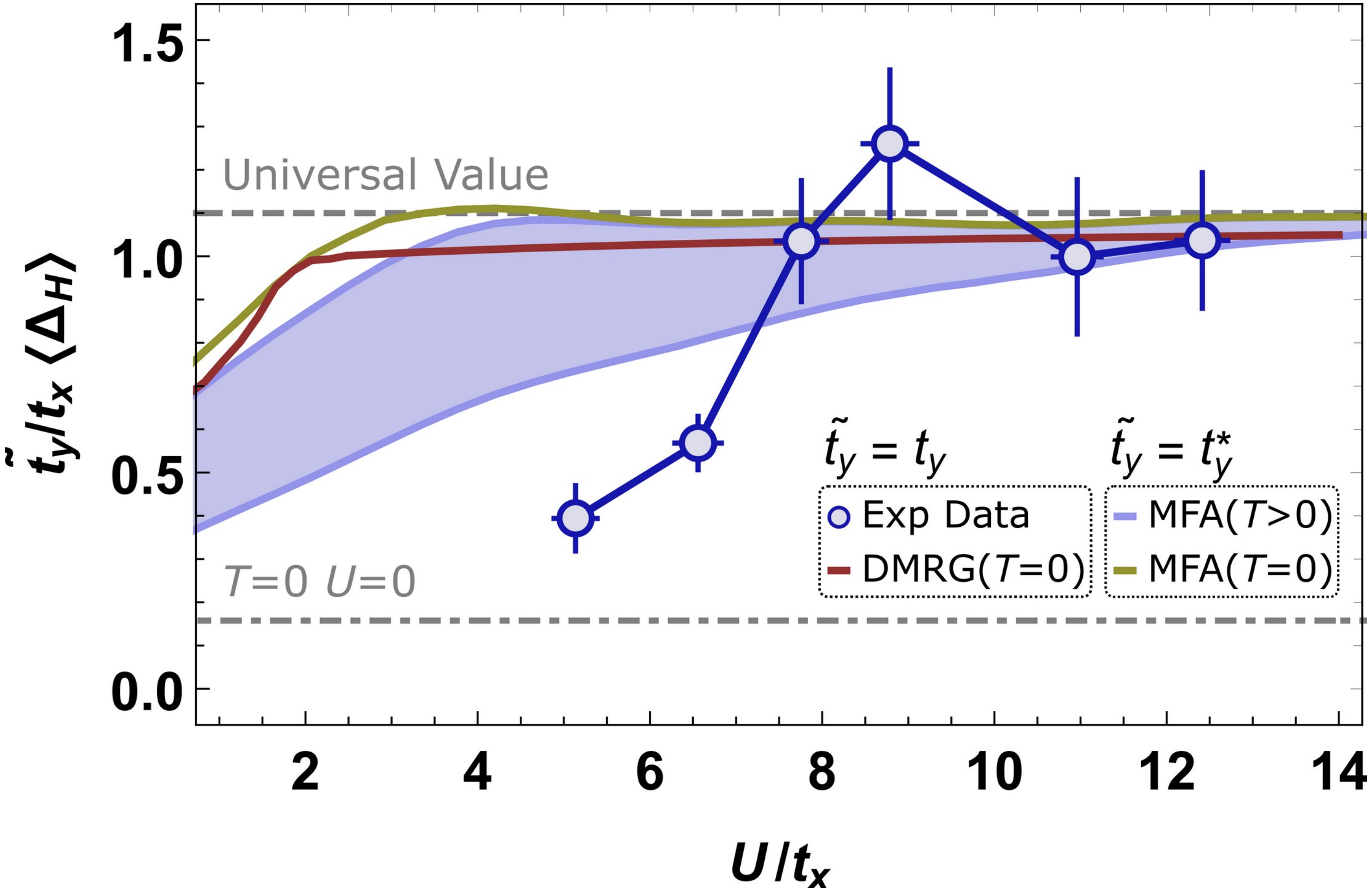
For $t_y \gg t_x$

$$\Delta_{\mathrm{H}} = 2\frac{t_x}{t_y}\left|\tan\left(\frac{\varphi}{2}\right)\right|$$

SIGNATURE OF A SINGLE-BAND METAL

$U = 6.56 t_x$

Universality driven by interactions



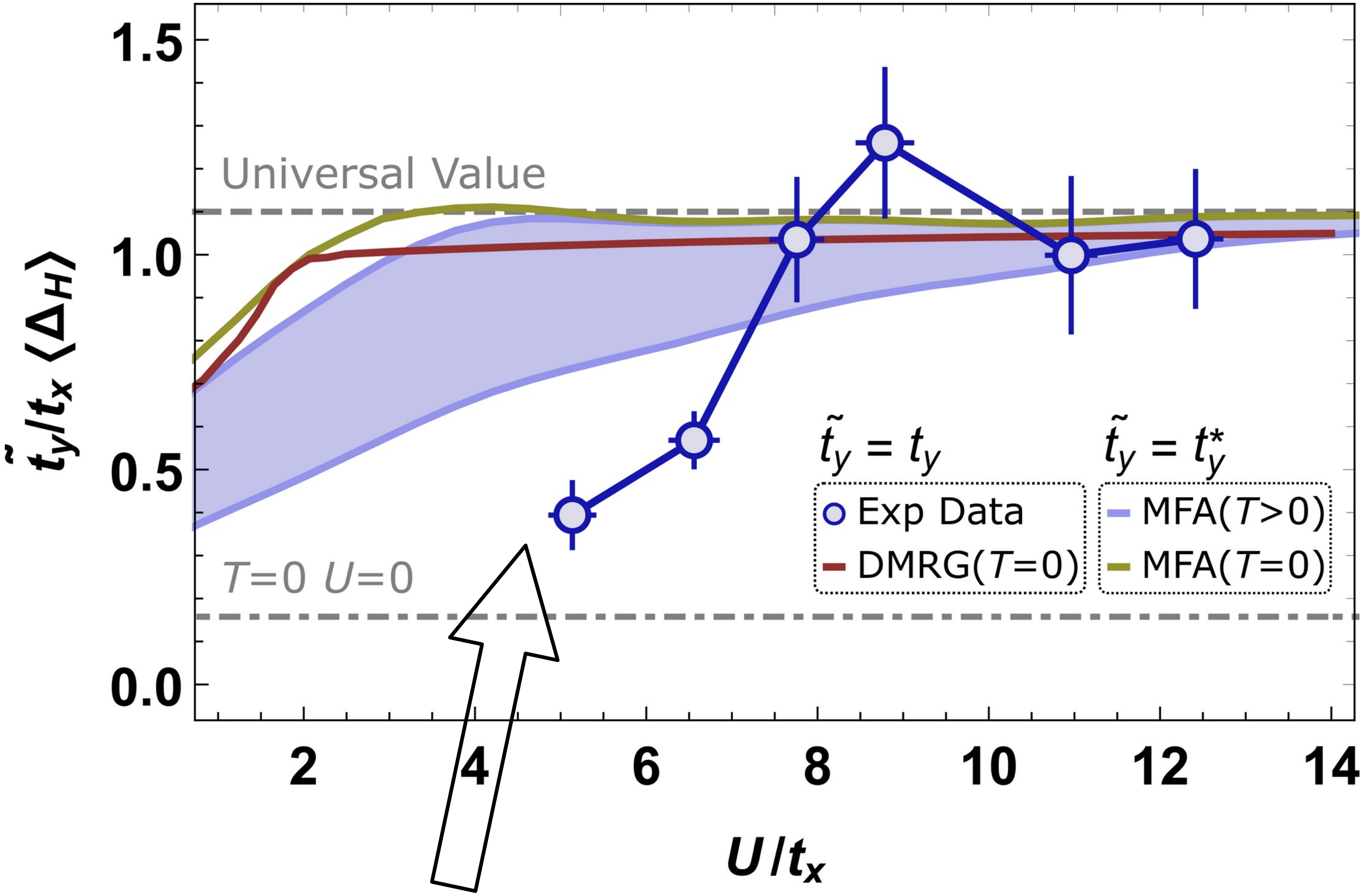
For $U \gg t_x$

The same value is reached by cranking up the interaction strength U

$$\Delta_{\mathrm{H}} = 2\frac{t_x}{t_y}\left|\tan\left(\frac{\varphi}{2}\right)\right|$$

$t_y = 1.15 t_x$

Universality driven by interactions



For $U \gg t_x$

The same value is reached by cranking up the interaction strength U

$$\Delta_{\mathrm{H}} = 2\frac{t_x}{t_y}\left|\tan\left(\frac{\varphi}{2}\right)\right|$$

Hard-to-compute regime where U, T and t_y are all of the same order

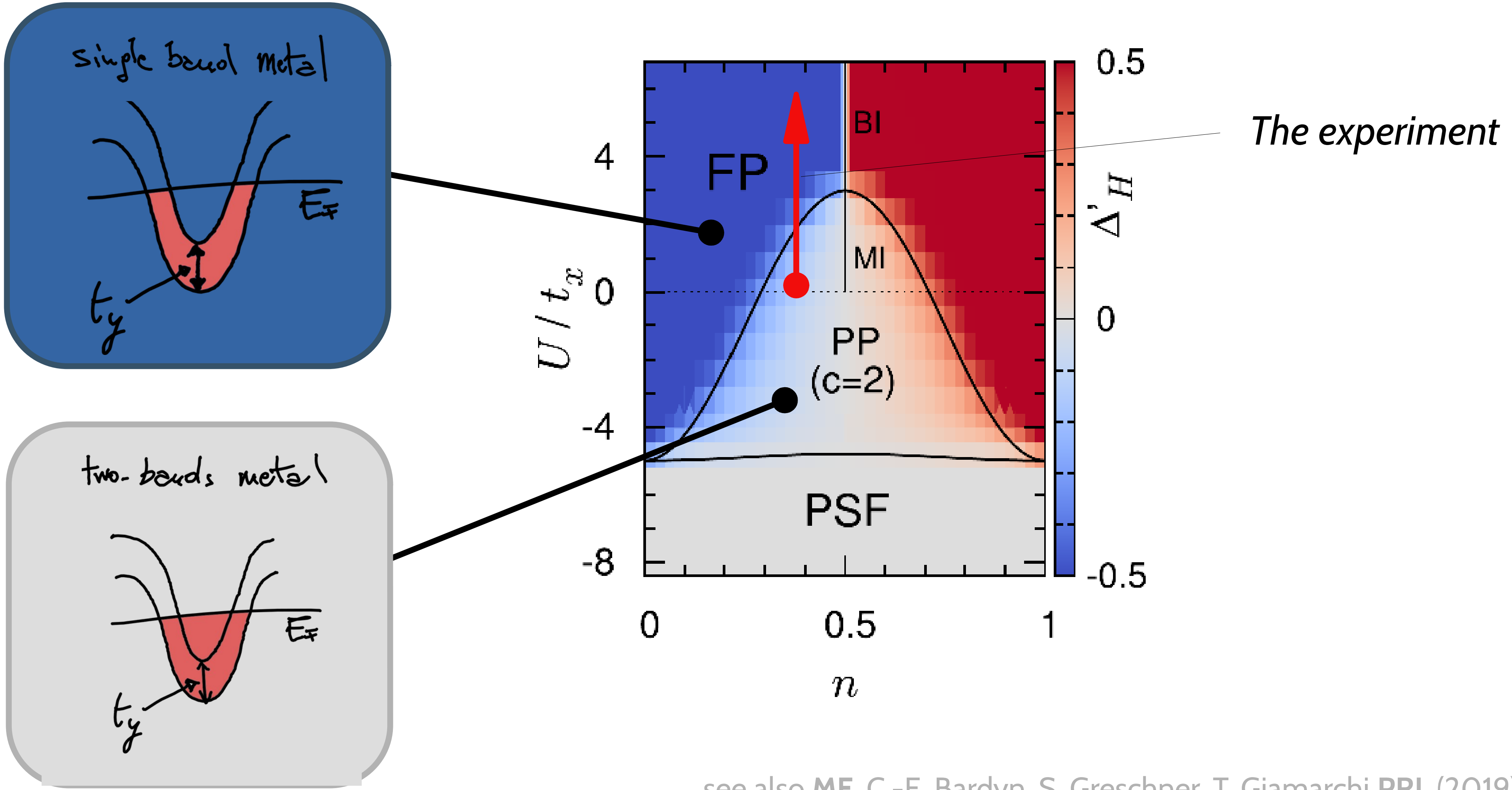
$t_y = 1.15 t_x$

PHYSICAL REVIEW LETTERS **122,** 083402 (2019)

Editors' Suggestion

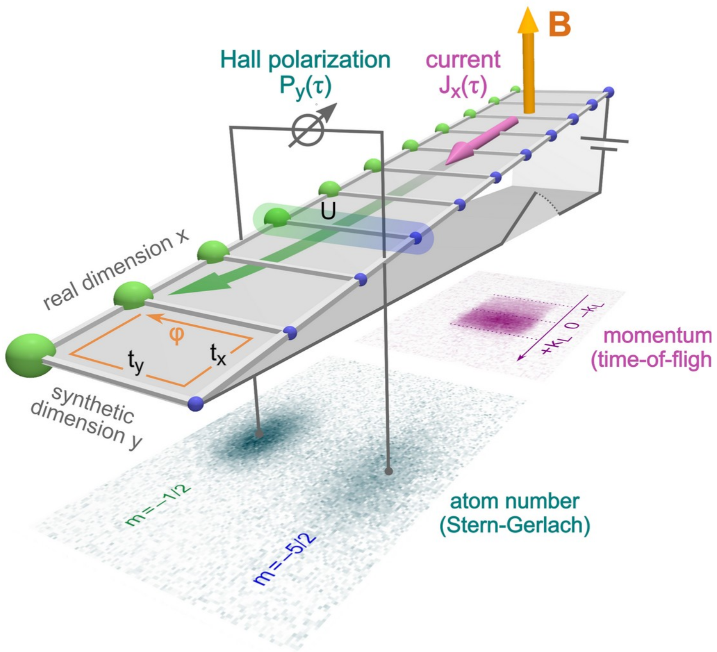
Universal Hall Response in Interacting Quantum Systems

Sebastian Greschner, Michele Filippone, and Thierry Giamarchi
Department of Quantum Matter Physics, University of Geneva, 1211 Geneva, Switzerland

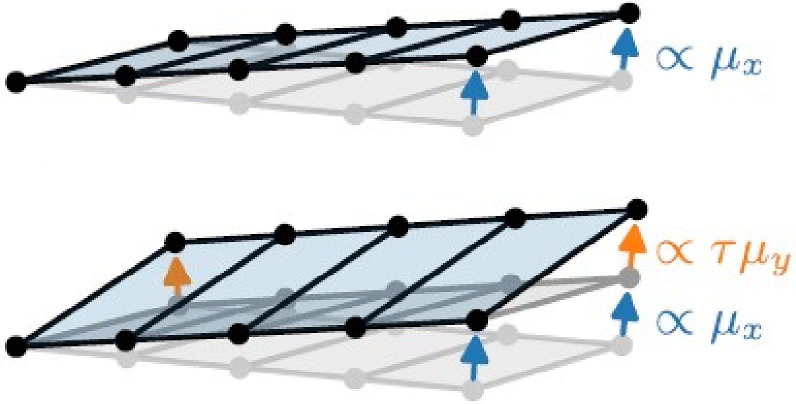


see also **MF**, C.-E. Bardyn, S. Greschner, T. Giamarchi **PRL** (2019)

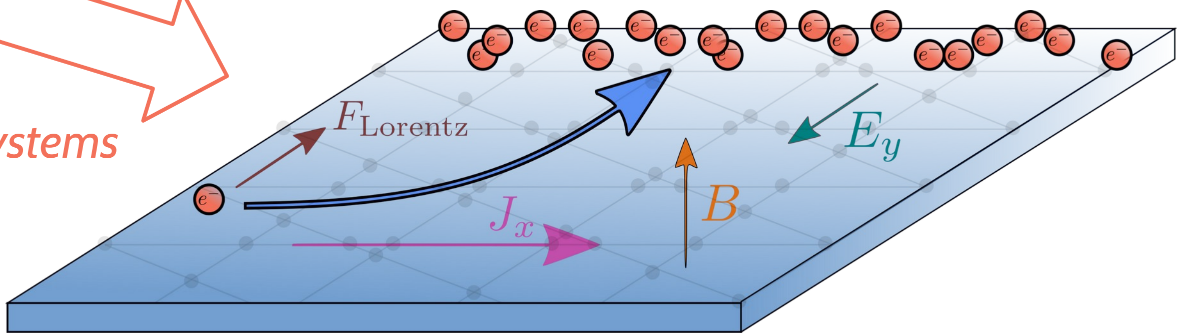
Perspective : voltage measurements



Our experiment

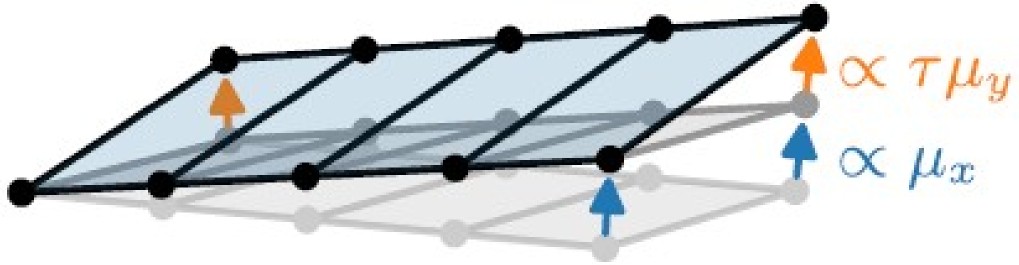


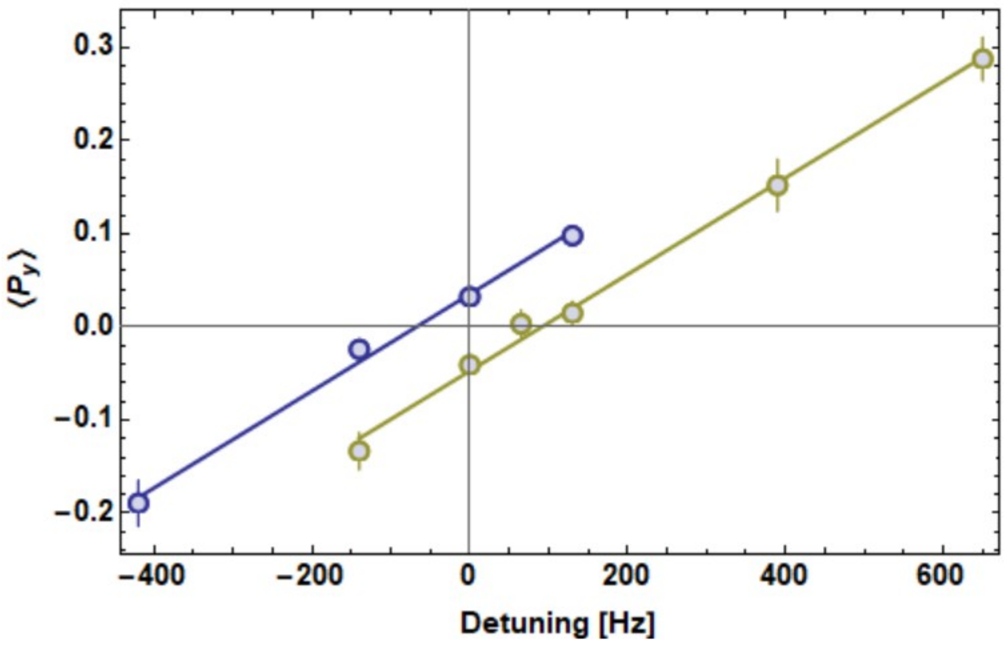
Solid state systems

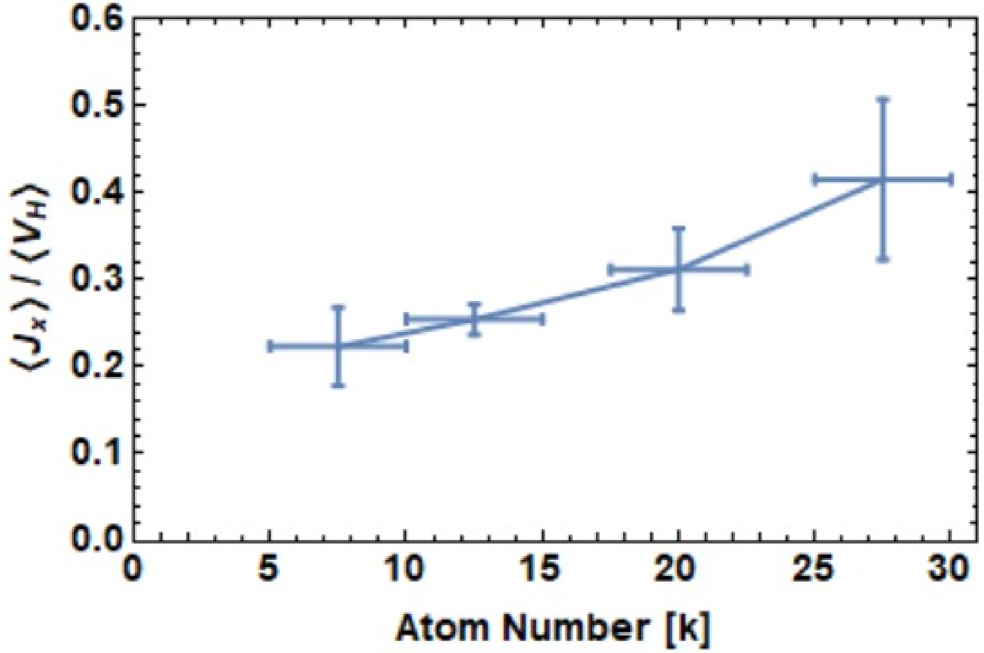


Buser, Greschner, Schollwöck Giamarchi PRL (2021)

Preliminary : voltage measurements

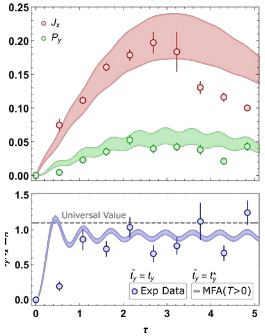


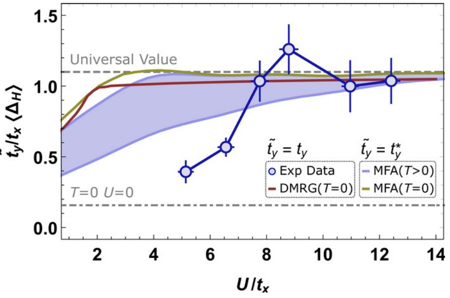




Conclusions

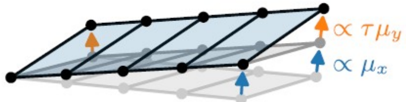
First observation of universal many-body effects on the Hall response of a controlled quantum simulator

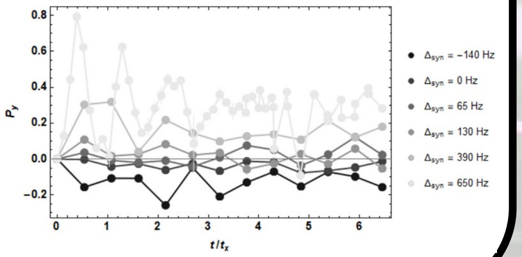




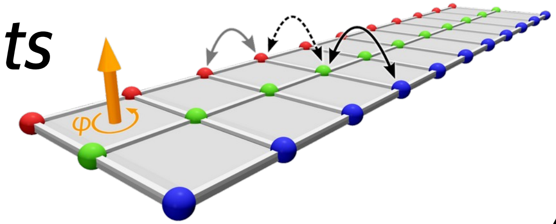
Perspectives

Measuring Hall voltages



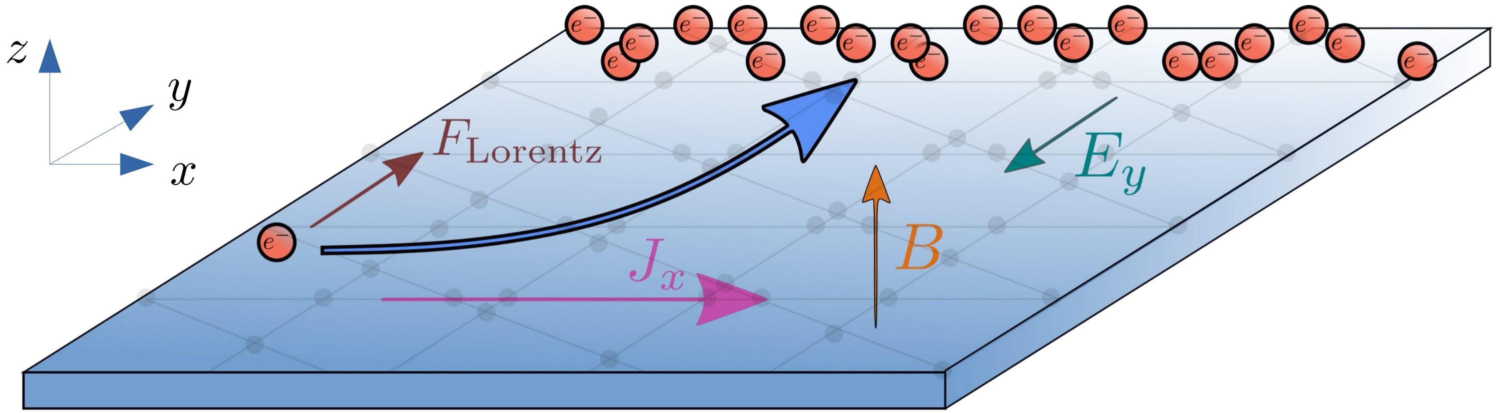


Addressing correlated topological phases in multi-leg experiments




Thanks !

The Hall effect : classics



From measuring the carrier density in metals...

Forces at work

$$F_{\text{Lorentz}} = J_x B$$
$$F_{\text{Electric}} = nqE_y$$

stationary condition

$$F_{\text{Electric}} + F_{\text{Lorentz}} = 0$$

Hall resistance

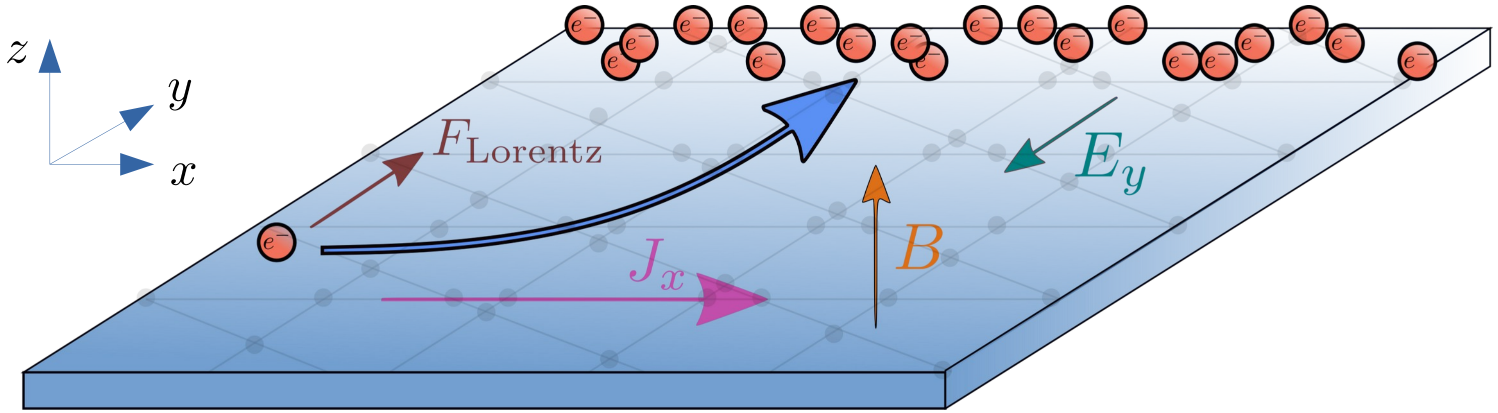
$$\rho_{\text{H}} = \rho_{xy} = \frac{E_y}{J_x} = -\frac{B}{nq}$$

Hall constant

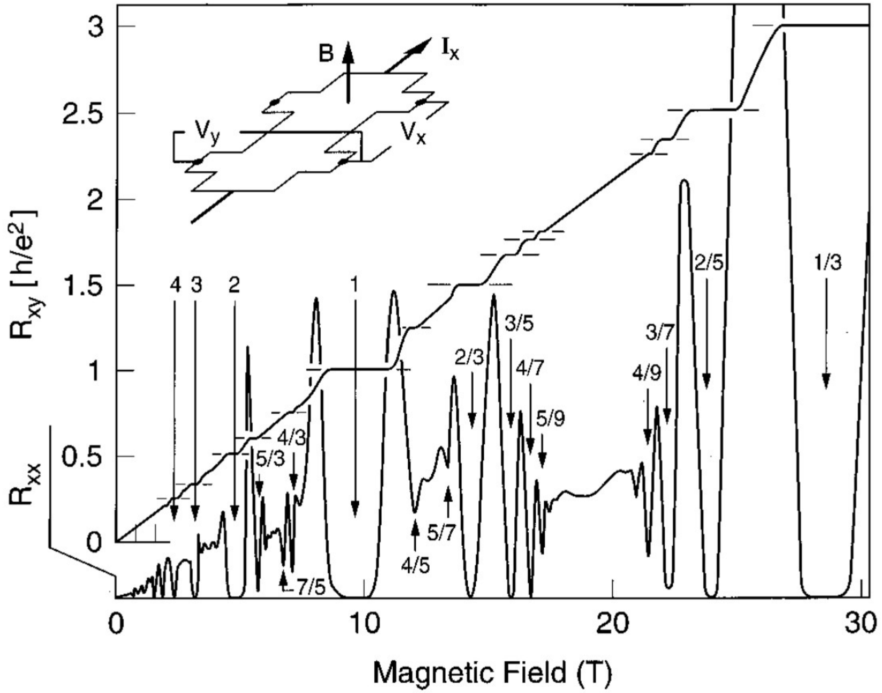
$$R_{\text{H}} = \frac{\rho_{\text{H}}}{B} = -\frac{1}{nq}$$

E. H. Hall, American Journal of Mathematics 2, 287 (1879)

The Hall effect : classics

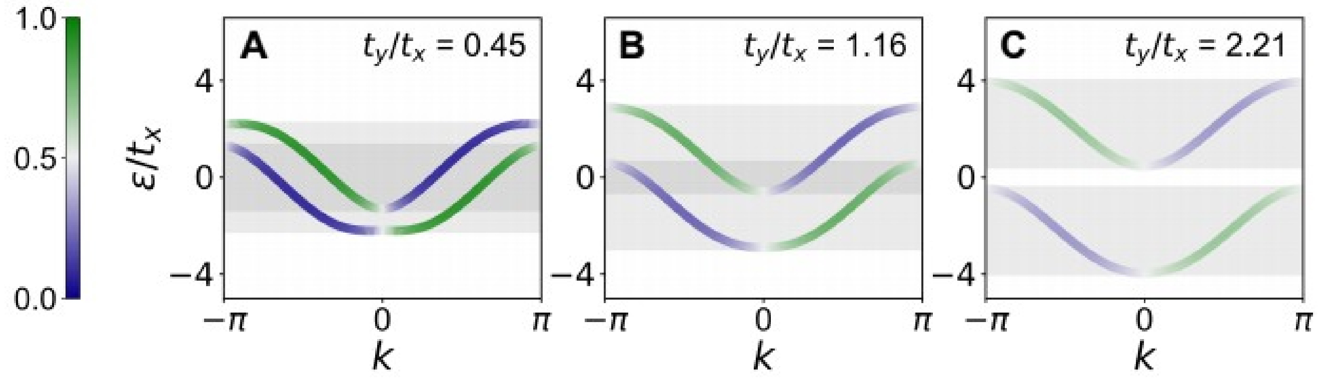


... to strongly correlated topological effects



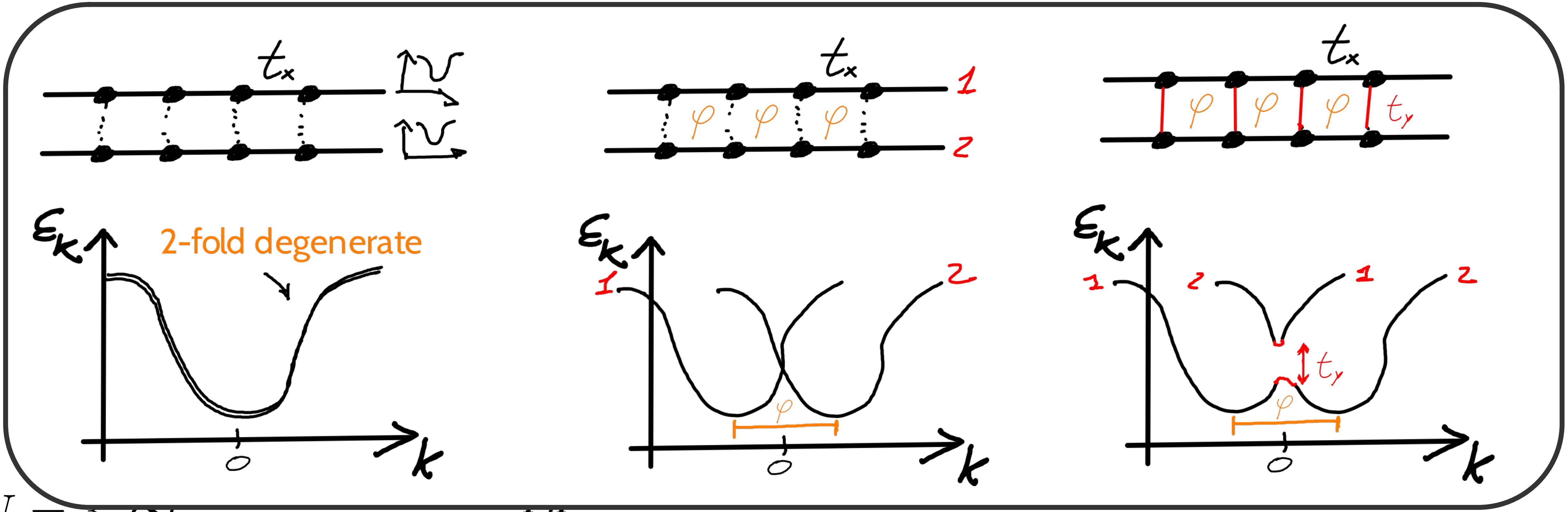
Eisenstein and Stormer **Science** (1990)

Transverse tunneling – t_y – dependence



Non-interacting 2-band spectrum

how to understand it



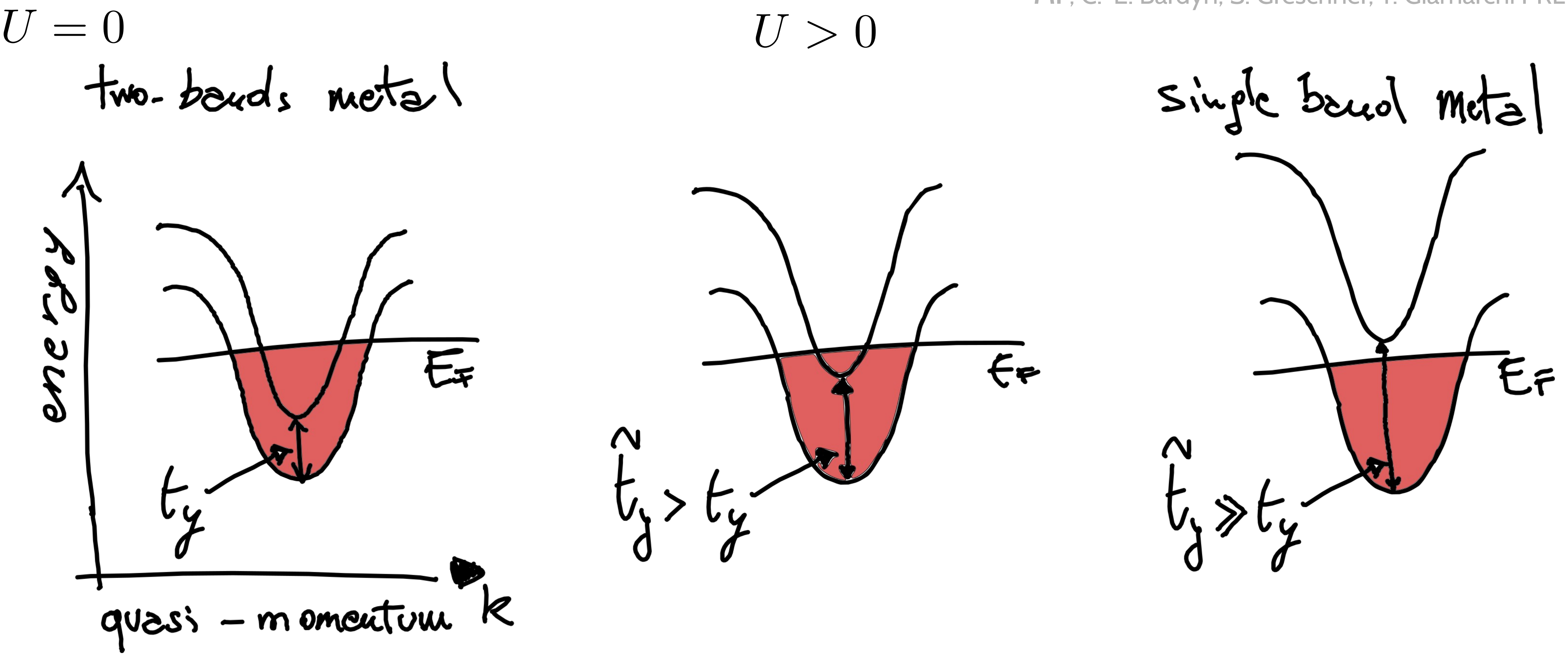
$U = 3.28t_x$

t_y/t_x

A strongly correlated stabilization of a single-band metal

and the limits of a mean-field analysis

S. Greschner, **MF**, T. Giamarchi PRL (2019)
MF, C.-E. Bardyn, S. Greschner, T. Giamarchi PRL (2019)



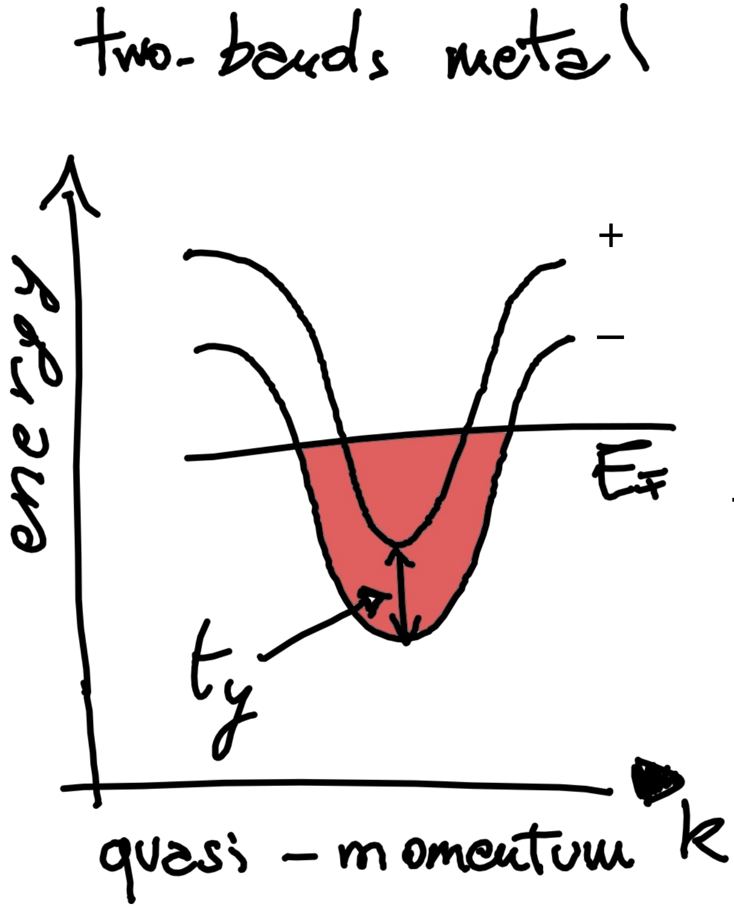
PROBLEM : The mean-field analysis predicts the **unobserved** suppression of $\Delta_{\mathrm{H}} \propto \frac{1}{\tilde{t}_y}$

A strongly correlated stabilization of a single-band metal

and the limits of a mean-field analysis

S. Greschner, **MF**, T. Giamarchi PRL (2019)
MF, C.-E. Bardyn, S. Greschner, T. Giamarchi PRL (2019)

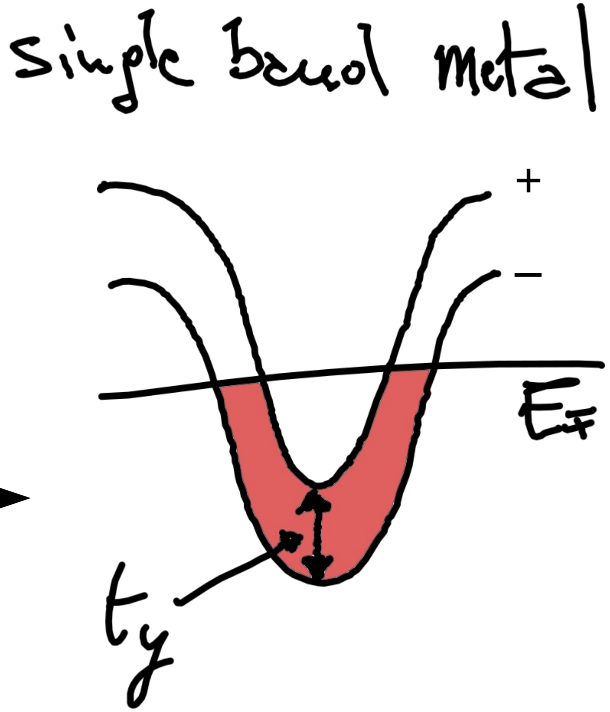
$U = 0$



$U > 0$

SU(2) symmetry of interactions

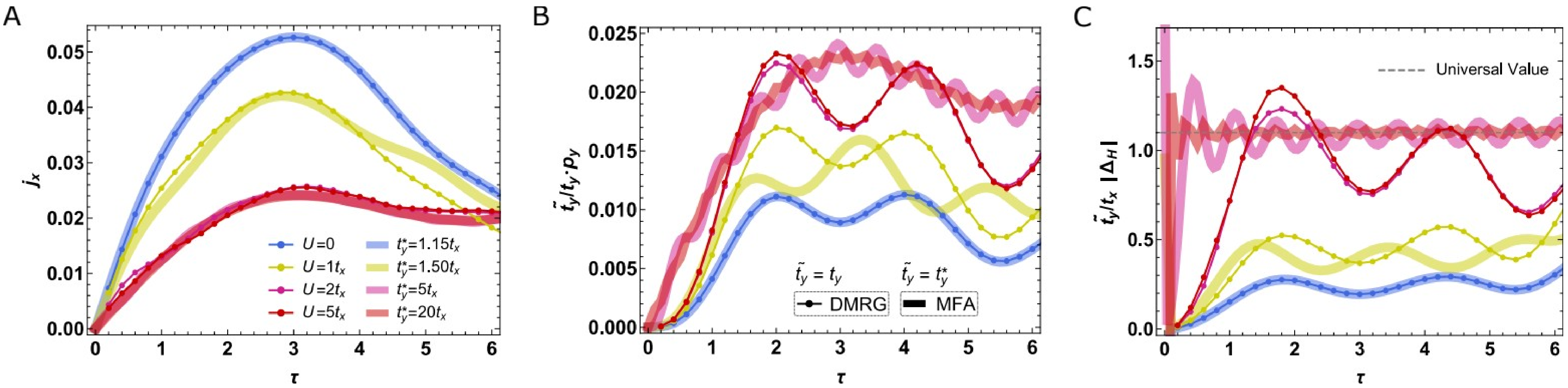
$$U \sum_j n_{j,0} n_{j,1} = U \sum_j n_{j,+} n_{j,-}$$



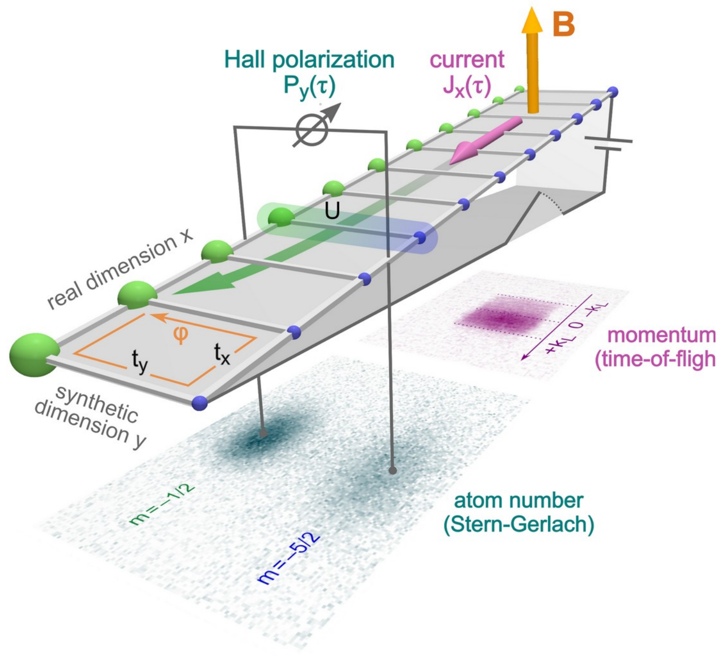
UNIVERSALITY WITH RESPECT TO INTERACTIONS

$$\Delta_{\mathrm{H}} = 2 \frac{t_x}{t_y} \left| \tan\left(\frac{\varphi}{2}\right) \right|$$

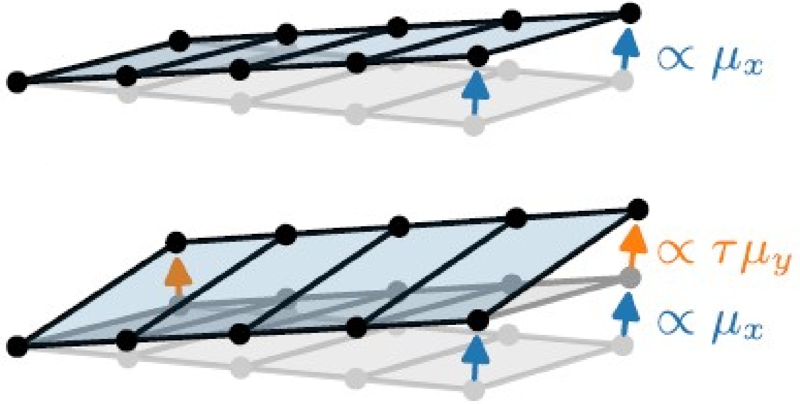
Dynamical difference between DMRG and Mean-Field



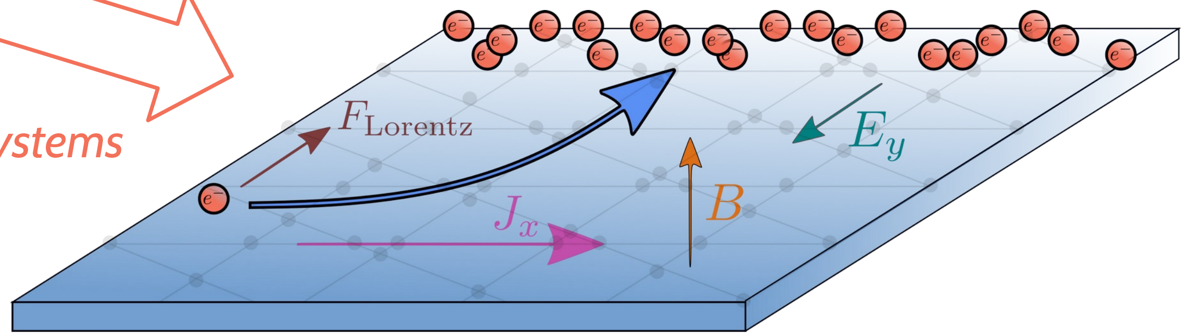
Perspective : voltage measurements



Our experiment

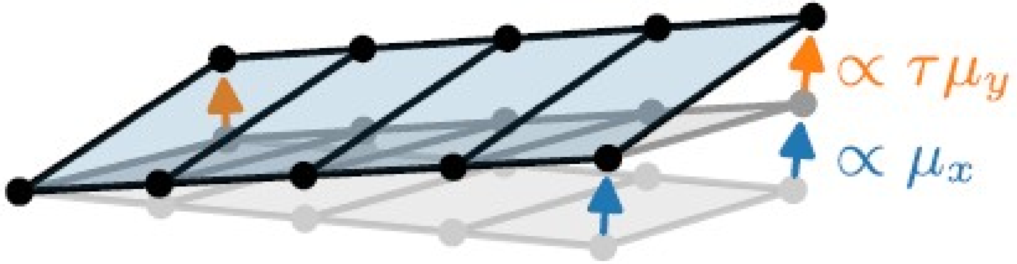


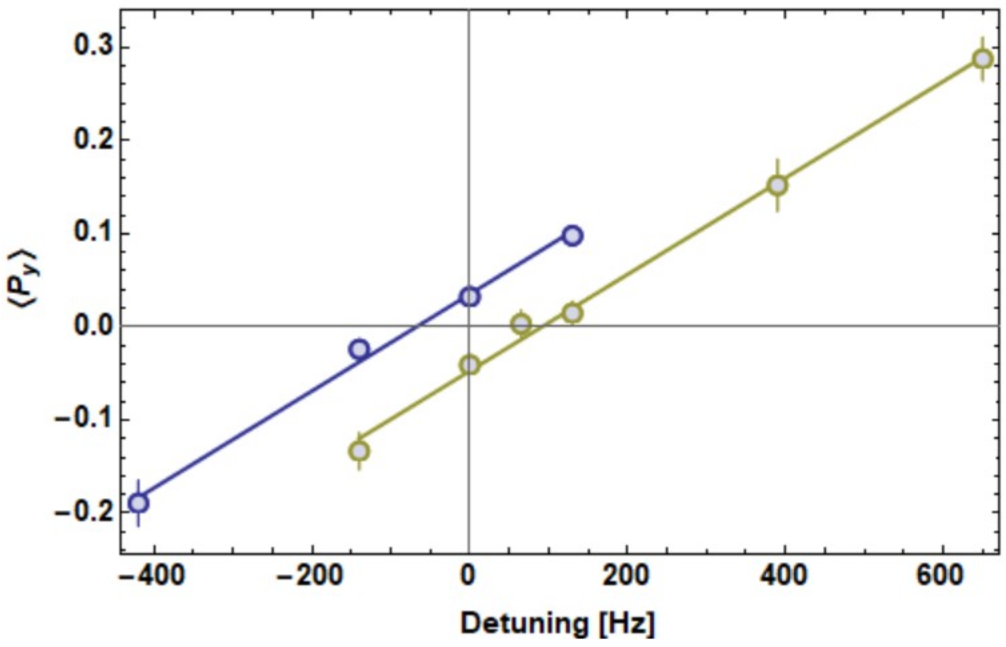
Solid state systems

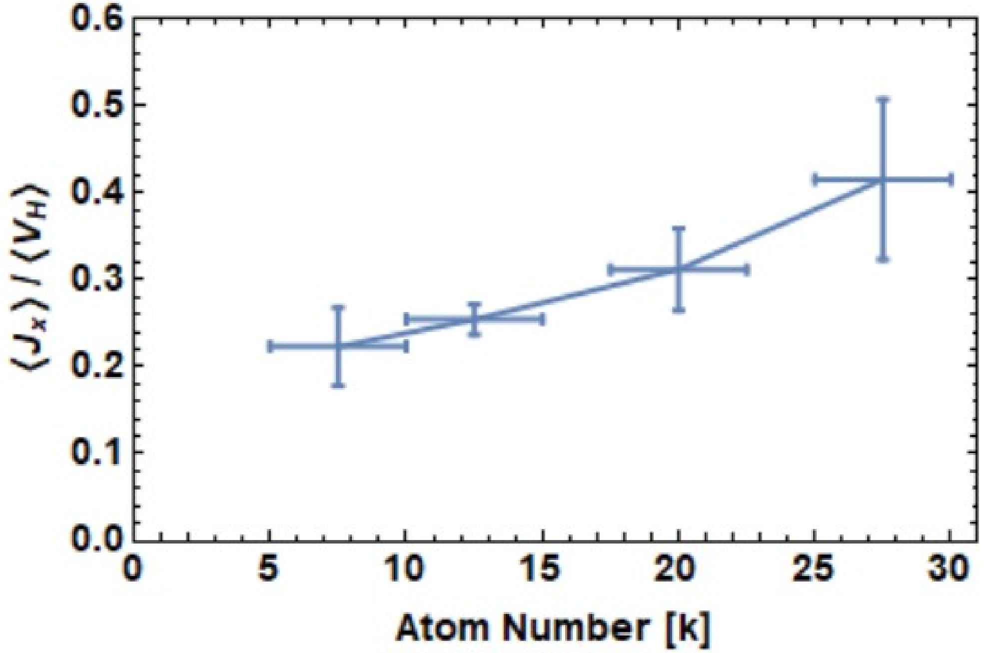


Buser, Greschner, Schollwöck Giamarchi PRL (2021)

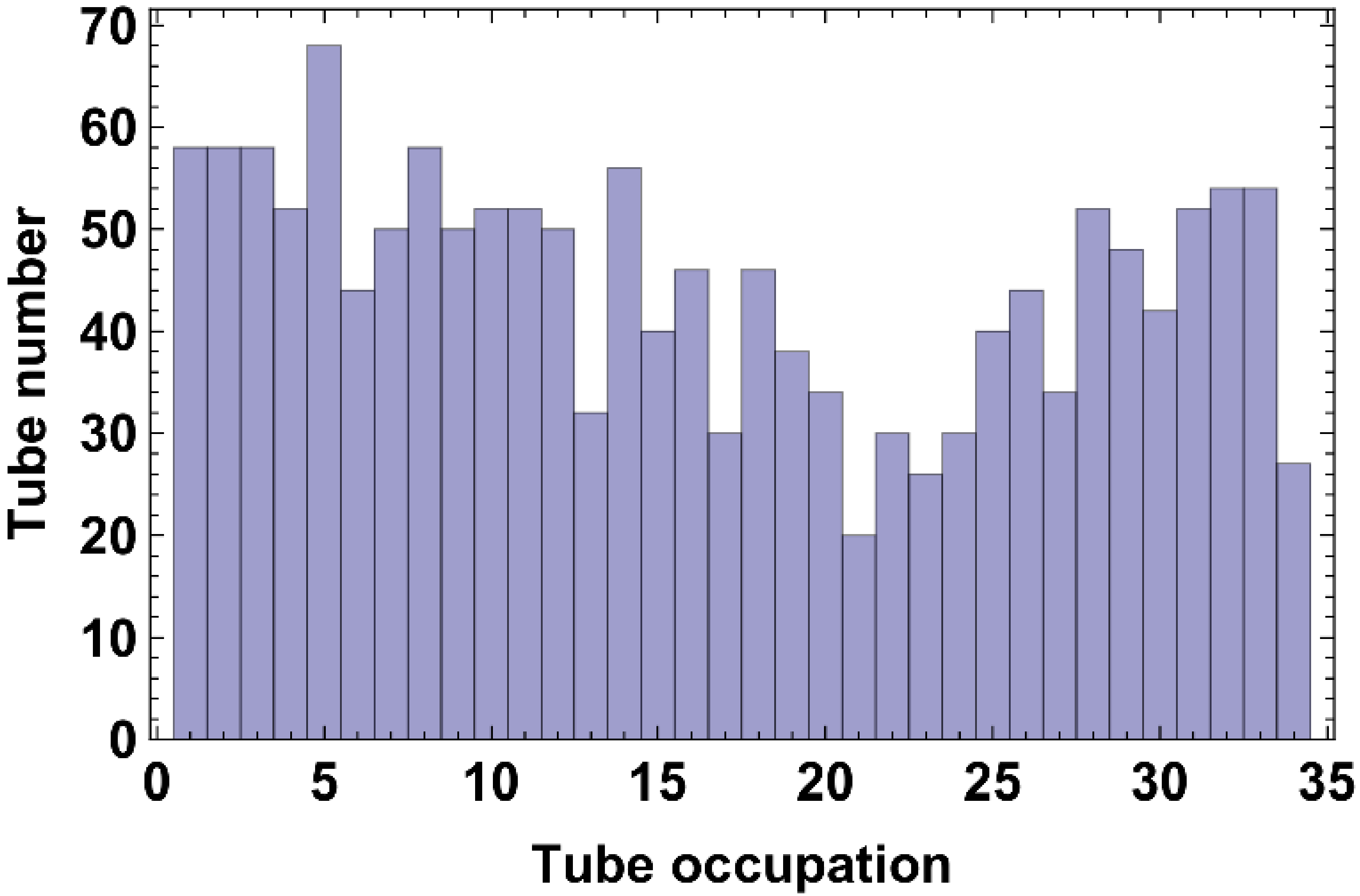
Preliminary : voltage measurements







Tube occupation distribution



Total ~ 25k atoms

Transition for different densities at T=0