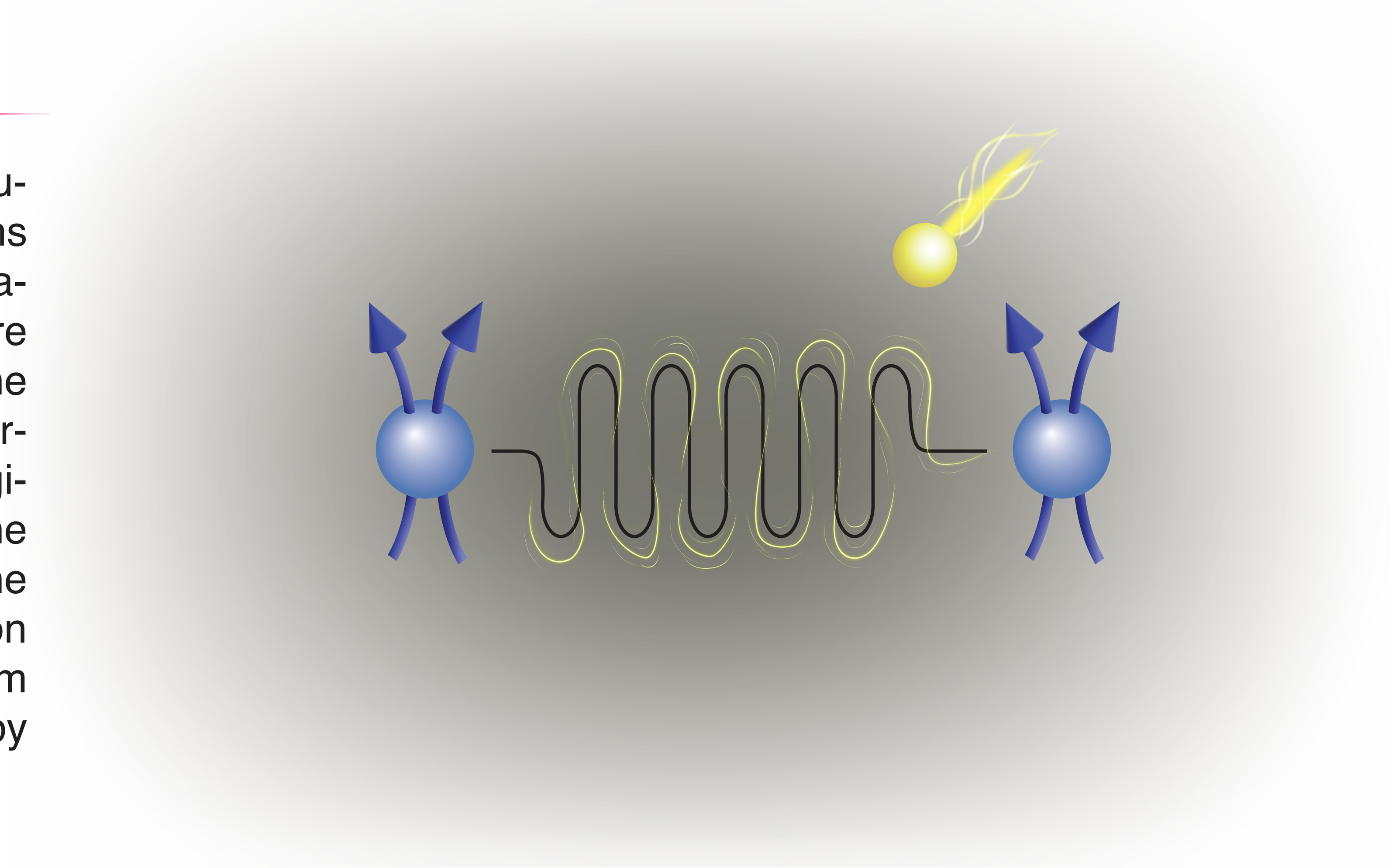
MICROWAVING QHS IN GRAPHENE

Aalto-yliopisto

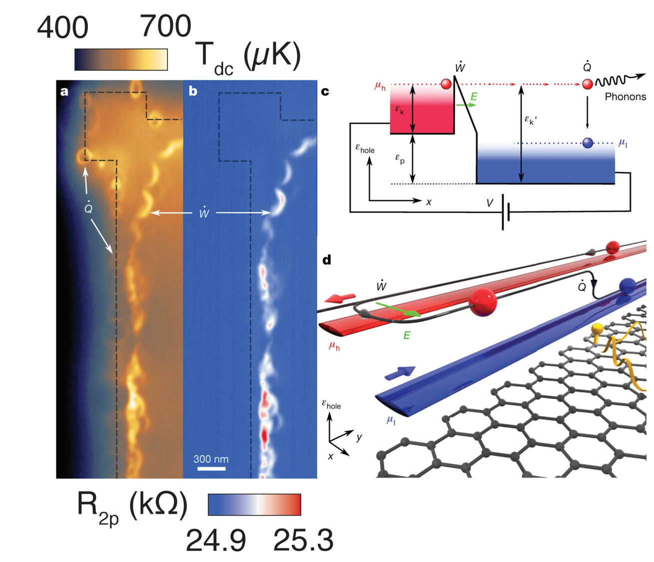
Kristiana Frei Nadarajah and Preeti Pandey
Low Temperature Laboratory, Departement of Applied Physics, Aalto University, Espoo, Finland

INTRODUCTION

Quantum computers store the information in qubits by the coherent manipulation of superposition states of quantum objects. Most conventional quantum computing platforms are sensitive to environmental perturbation leading to decoherence and loss of information. Non-Abelian anyons provide topological protection against decoherence where quantum information is stored in the so called braid operations: non-local winding of the topological excitations in space-time [1]. However the non-local nature makes transferring information between topological qubits more difficult. An interface between topological qubits and conventional quantum bits will allow for the combination of the best of the two worlds, making such a hybrid platform for quantum computing highly desirable. The first step towards this platform is the development of a microwave probe for non-Abelion anyons, as coupling qubits via microwaves forms an integral part of modern-day quantum computing technologies [2]. This is the major goal of this proposal, where we start by studying topological states formed in the graphene bulk via microwave photons.

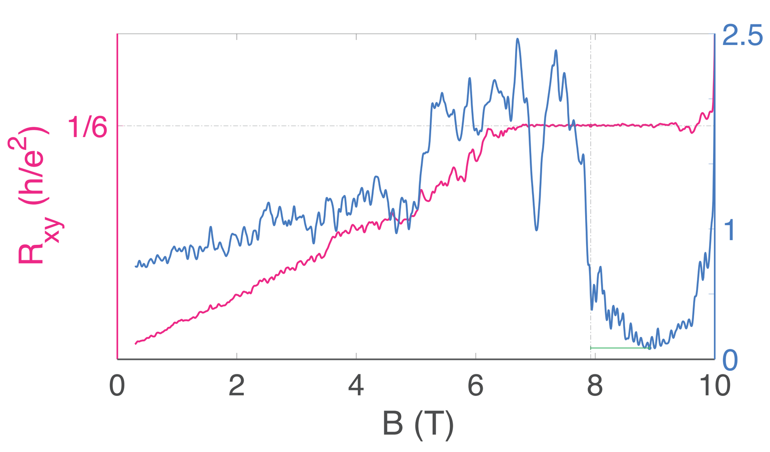


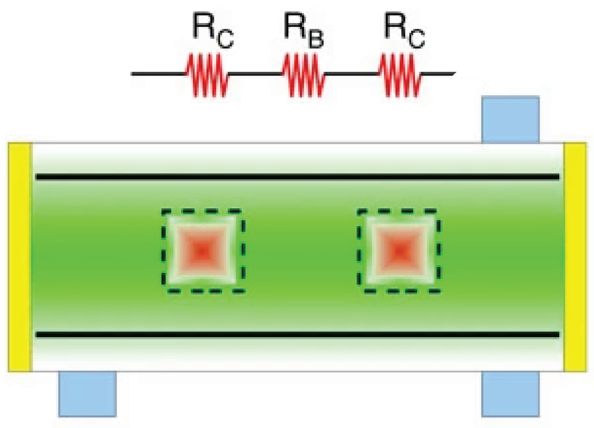
THE BIG UNKNOWNS



How do the edges of graphene affect QHS?

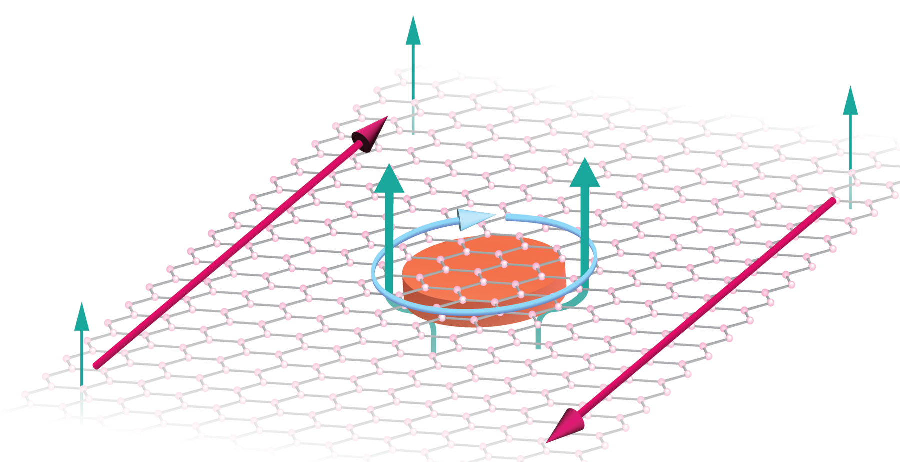
The dissipative phenomenon of the topological breakdown of quantum Hall states (QHS) stems from lattice defects at the physical edges of graphene [3-4].
A mismatch between the bulk and edge states has been experimentally observed.





Measuring quantized transport does not give enough information about the states in the bulk. One approach to study the bulk would be placing contacts within the bulk [5]. But since this alters the topology the resulting measurement is not conclusive.

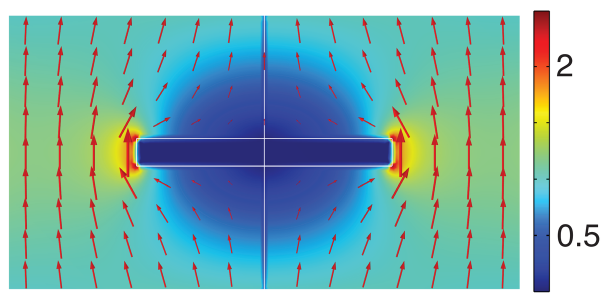
CONSTRUCTING ARTIFICIAL EDGES



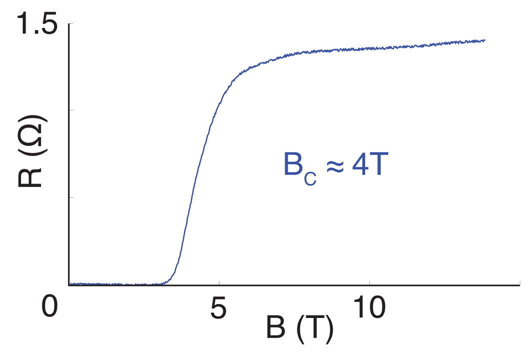
To escape the disordered edges we need a way to manipulate the states in the bulk: using a superconductor!

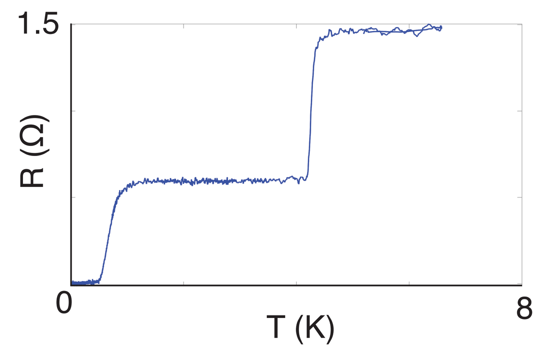
$$\nu = \frac{nh}{eB}$$

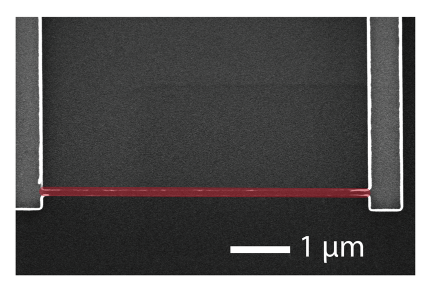
Changing the magnetic field will change the filling factor



Simulation results of the Meissner effect in a superconducting disk. As seen in the figure, there will be no magnetic field passing through the disk and around the edges the flux density is the highest [6].





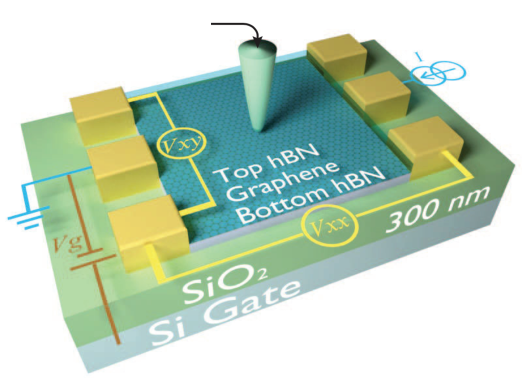


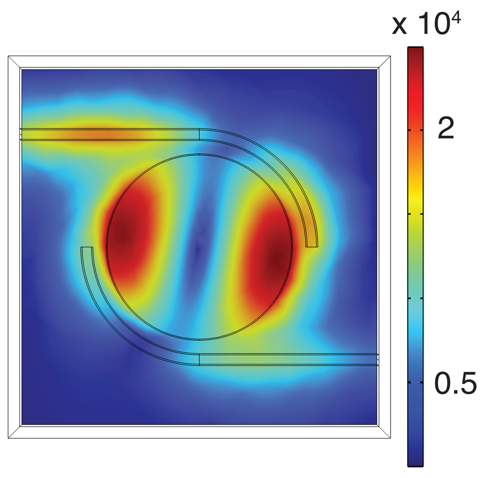
SEM image of a MoRe wire

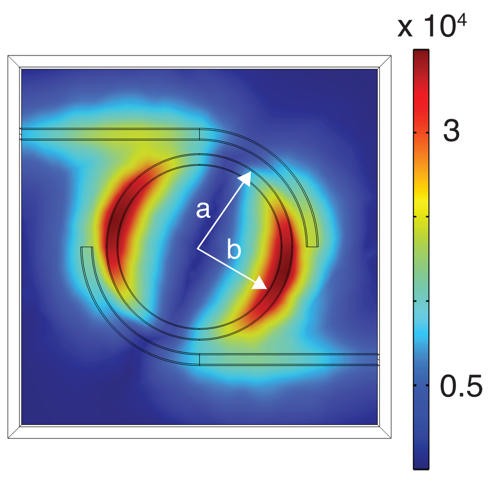
COUPLING QHE TO MICROWAVES

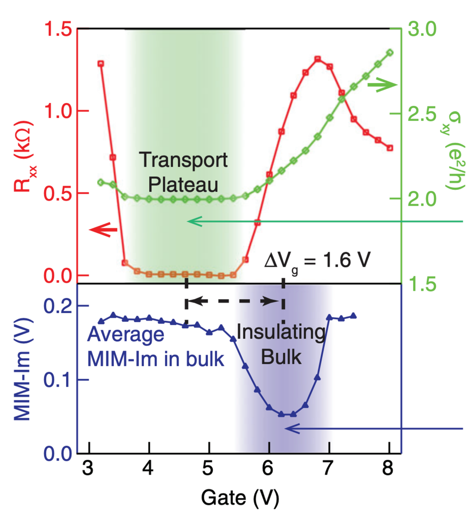
Now the question is, how do we measure the edge states in the bulk?

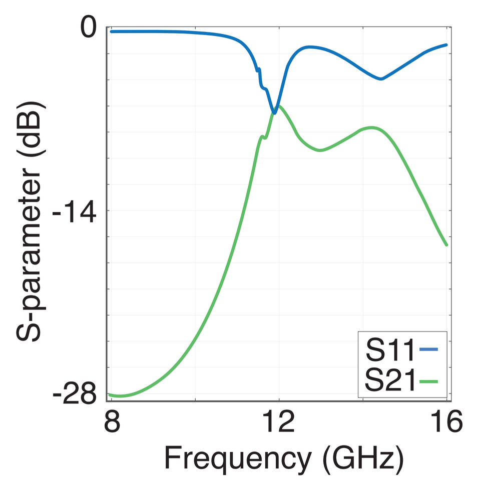
→ **Microwave photons** $f_R = \frac{c}{\frac{a-b}{2}\sqrt{\epsilon_{eff}}}$ *Resonance frequency of a ring*

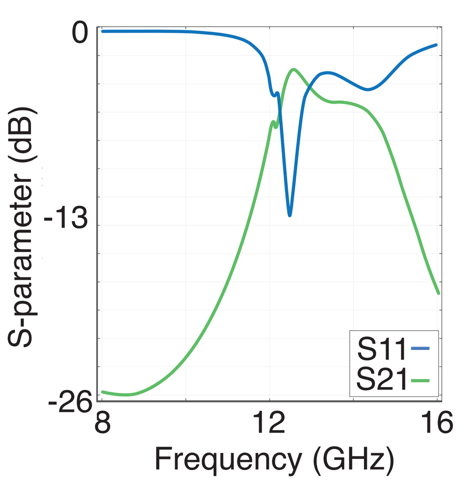






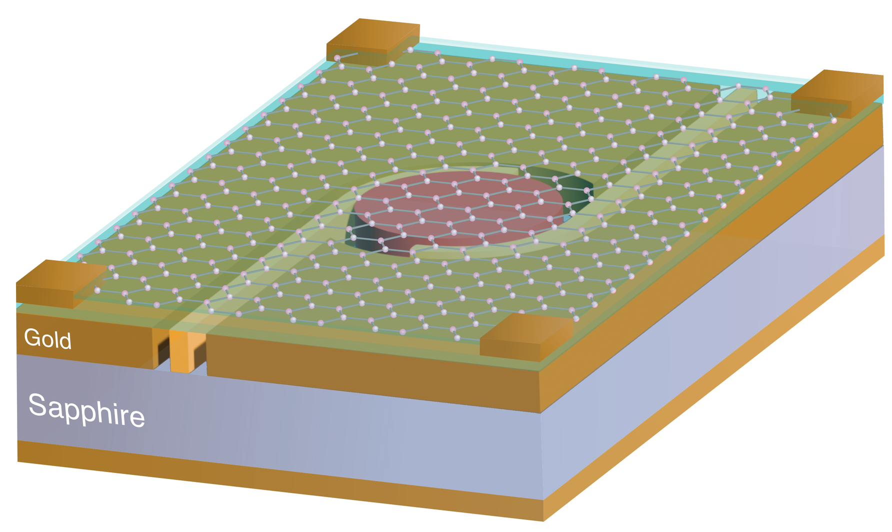




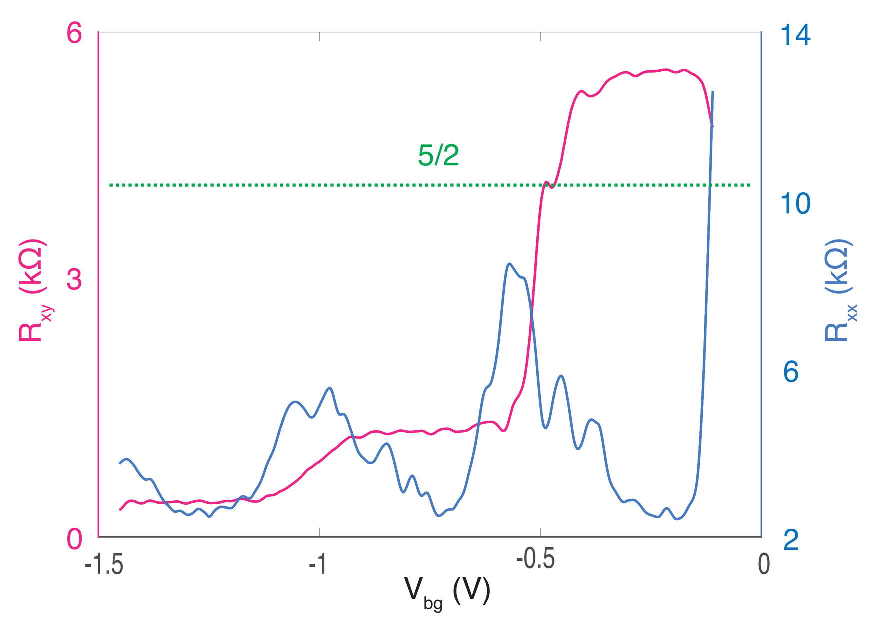


QHS in the bulk can be detected using microwave signals [7].
In our sample, the area of the graphene above the superconductor will act as a metal disk. Only when QHS are formed, this disk becomes a ring which represents the dissipationless edge channels. The simualtions show how the frequency response will differ.

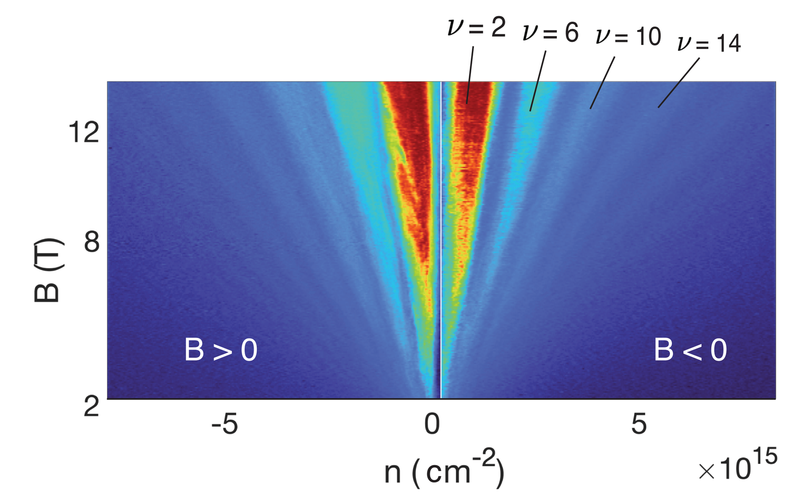
ONGOING WORK

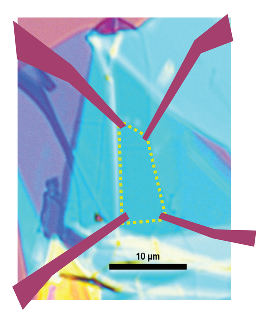


Proposed sample structure: co-planar waveguide on sapphire substrate with a superconducting disk. A stack of hBN-graphene-hBN-graphite is placed on top where hBN acts as a barrier to the ground plane and gives high electron mobility in graphene. A graphite top gate (not pictured) will be used to tune the charge density of the whole sample. 1D contacts are placed on the stack to measure QH transport.



Measurement data on QH transport. Non-abelian state $\nu = 5/2$ is visible.





Representative image of a stack with 1D contacts

To be continued...

REFERENCES

[1] Chetan Nayak et al. Rev. Mod. Physics. 80, 1083 (2008)
[2] J. C. Bardin et al. IEEE Journal of Microwaves 1, 403 (2021)
[3] Marguerite, A. et al. Nature 575, 628, (2019)
[4] Moreau, N et al. Nat Commun 12, 4265 (2021)
[5] Kendirlik, E., Sirt, S., Kalkan, S. et al. Nat Commun 8, 14082 (2017)
[6] Gulian, Armen. "Shortcut to Superconductivity" (2020)
[7] Cui, Yong-Tao et al. Phys. Rev. Lett. 117, 186601 (2016)

FICORE Finnish Indian Consortia for Research and Education
ACADEMY OF FINLAND