The final report (with selection of topics)

One of the scopes of this course is to be able to gain a precise and deep understanding of modern research topics in condensed matter. To complete the course you are asked to study a topic of your choice (related to the subjects of the course) and produce a report about it.

The aim of the report is to present the framework of the subject you are addressing, the main ideas and the purposes of the article you are analyzing.

Besides this, you may present in detail some of the key arguments of the paper you have chosen, for example by presenting detailed calculations, or alternative derivations of what you read.

This final report should be about 6 pages long, and you are also free of presenting your personal opinions about it. Why is it important? Is there anything that could be done better?

In general, I ask you to produce a report which includes:

- An introduction: about the framework of the paper, and its main purposes;
- A technical part: about details that you liked, neat calculations or arguments you found interesting. You are not asked to redo all possible calculations of the paper you have chosen, but I appreciate if you demonstrate your technical understanding of some of the details;
- A conclusion which summarizes the main results, how this research may evolve or evolved after the paper and your personal impressions if you wish.

All these parts must be clearly and rigorously written (for instance, you must define all the elements in the equations you use, and describe the figures you introduce with suitable captions or in the main text). Furthermore, this 6-page report should be self-contained, such that one of your course colleagues, for example, could read and understand it without continuously referring to the paper you have chosen or the literature. You can certainly add references to argument your statements or to indicate the reader where he can find technical details; but your line of thoughts and the logical structure of the report must be clear without the need of reading additional material.

In the following you find some suggested topics. For some of them I list suggested papers for these topics, for the others, ask me! I will update the list from time to time, and you are free of proposing subjects on your own. In the case of long papers, you will focus on specific parts we will decide together.

- Google and Kitaev realized the ground state of a surface code:
  https://arxiv.org/pdf/2104.01180.pdf. Explain how.
  See also section 2 in https://arxiv.org/pdf/2110.02020.pdf
- Toric code at finite temperature. The toric code suffers from "thermal fragility". This is addressed in a few papers, for example:
  https://arxiv.org/pdf/0709.2717.pdf ;

https://arxiv.org/pdf/cond-mat/0702377.pdf ;
https://arxiv.org/pdf/quant-ph/0110143.pdf .

- $\mathbb{Z}_N$ toric code:
  https://arxiv.org/abs/quant-ph/0609070 ;
  https://arxiv.org/pdf/1110.3632.pdf

- Perturbations of the toric code and the $\mathbb{Z}_2$ lattice gauge theory (several reference by Fradkin on LGTs, or more modern discussions about the perturbations of the toric code. This offers links to particle physics topics)

- Kitaev's honeycomb lattice model:
  https://arxiv.org/abs/cond-mat/0506438

- From Majorana / Josephson junction arrays to surface codes:
  https://arxiv.org/abs/1606.08408

- An RG/Luttinger approach to the transport mediated by Majorana modes (elegant and simple theoretical modelling of transport phenomena often observed in QDEV's experiments):
  https://arxiv.org/abs/1203.4818

- Is there life beyond Majoranas? Parafermions (this answers the question "What if I have a $\mathbb{Z}_N$ symmetry"?).
  General theory: https://arxiv.org/abs/1209.0472 .
  How can we realize them? https://arxiv.org/abs/1204.5479

- Topological order beyond the toric code: introduction to quantum-double models or to the string-net Wen-levin model [https://arxiv.org/abs/cond-mat/0404617] (Mathematically tough models, with links to particle physics and topological field theory. The main references will be Kitaev for the quantum doubles and Levin-Wen for the string nets. The Levin-Wen model can also be seen from the eyes of quantum information, as a code...)

- Surface codes as error correcting codes. See the review Fowler et al., arXiv:1208.0928. (There are also many more recent works.)

- Twist defects in the toric code and Majorana modes.
  See: https://arxiv.org/abs/1508.04166
  https://journals.aps.org/prx/abstract/10.1103/PhysRevX.7.021029

- Google experiment on twist defects in the surface codes and Majorana modes.

- Hofstadter model and the TKNN formula: Phys. Rev. Lett. 49, 405 (1982) [Nobel prize paper]

- Topological (Thouless) quantum pumping: for instance Phys. Rev. B 27, 6083 (1983).

- Weyl semimetals, namely, the simplest example of a 3D gapless topological phase of matter.
  See, for instance, https://arxiv.org/abs/1105.5138.
- 2D p-wave superconductors (Several important references to choose from)
- Engineering 2D p-wave superconductors from s-wave SC, and Majoranas (Fu and Kane PRL 100, 096407 (2009); arXiv:0707.1692)
- Superfluid - Mott insulator phase transition in 1D chains of ultracold atoms (Bosonization, Commensurate/Incommensurate phase transition: Phys. Rev. Lett. 90, 130401 [2003])
- Ladder models of ultracold bosons (based on bosonization)
- Ladder models and fractional quantum Hall physics (based on bosonization)
- Wire deconstruction of fractional quantum Hall physics (based on bosonization)
- Recent experimental results on the statistics of anyons in FQHE (for example arXiv:1905.10248, or other works)
- Non-Abelian Berry connections: theory (Wilczek and Zee) and experiments