Master 2: ***International Centre for Fundamental Physics***

INTERNSHIP PROPOSAL

Laboratoire Kastler Brossel & LPENS
Internship directors: Félix Werner and Kris Van Houcke
werner@lkb.ens.fr / kris.van.houcke@phys.ens.fr 0144271422 / 0144323474
Internship location: Collège de France Thesis possibility after internship: YES
Funding for the PhD: NO (need to apply for EDPIF scholarship)

Diagrammatic Monte Carlo study of high-temperature superconductivity

Strongly correlated fermions are ubiquitous in various contexts: electrons in solids or molecules, nucleons in nuclei or neutron stars, quarks in QCD. Our understanding of such systems is limited by the difficulty to compute their properties in a reliable and unbiased way. For conventional quantum Monte Carlo methods, the computational time generically grows exponentially with the number of fermions, due to the "fermion sign problem".

The situation is fundamentally different with connected Feynman diagrams, which can be computed directly in the thermodynamic limit. In contrast to usual diagrammatic calculations which are limited to low orders, the idea of the *diagrammatic Monte Carlo* approach is to evaluate high enough orders to control the series-truncation error. This allowed us to obtain results for strongly correlated Fermi gases which served as benchmarks for cold atom experiments [1]. More recently, we extended the method to superconducting phases, and studied the *s*-wave superconducting phase of the attractive Hubbard model [2].

The goal of this PhD project is to study *d*-wave superconductivity in the repulsive Hubbard model and its extensions. This long-standing subject is relevant to high-T_c cuprate superconductors and to cold atoms in optical lattices. Recent numerical studies indicate that the repulsive Hubbard model (with next-nearest neighbor hopping) does host a *d*-wave superconducting phase which also breaks translational invariance [3]. In order to perform unbiased computations in the thermodynamic limit, we will use a new approach, currently developed by our postdoc Nils Caci in collaboration with Riccardo Rossi (EPFL), which combines the "connected determinant" algorithm of Ref. [4] with an algebraic automatic differentiation framework.

The internship will consist in preliminary studies for the PhD project.

---

[1] Rossi *et al.*, PRL 121, 130405 (2018); Rossi *et al.*, PRL 121, 130406 (2018); Van Houcke *et al.*, Nature Phys. 8, 366 (2012)
[2] Spada *et al.*, arXiv:2103.12038
[3] Xu *et al.*, Science **384**, 637 (2024)
[4] Rossi, PRL **119**, 045701 (2017)

Condensed Matter Physics: YES Soft Matter and Biological Physics: NO
Quantum Physics: YES Theoretical Physics: YES