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)

Study of strongly correlated fermions via stochastic evaluation of Feynman diagrams

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 for infinite volume. In contrast to usual diagrammatic calculations, we control the series-truncation error by going to high orders. To this end we develop Monte Carlo algorithms to efficiently sample diagrammatic series. In the cases where the series diverges, we study its the large-order asymptotic behavior, and use it to construct a resummation method capable of transforming the divergent series into a result that converges towards the exact physical value (in the limit of infinite truncation-order).

Using this program, we studied spin-1/2 non-relativistic fermions in 3D with contact interactions of infinite scattering length, the so-called unitary Fermi gas [1-3]. Apart from being qualitatively relevant for neutron stars, the unitary gas model accurately describes experiments on ultracold atomic gases conducted in several labs (LKB, MIT, Hamburg, Technion, Yale…) which gives opportunities for direct theory-experiment comparison.

A first PhD project is to extend these computations to new regimes –in particular the polarized regime, where conventional QMC suffers from the sign problem– and new observables –motivated by recent and ongoing experiments. On the algorithmic side, we plan to make use of the approach of [4], which has several advantages over the algorithm described in [5] that we have used so far. Another PhD project is to study the unitary Fermi gas with a single spin-down particle interacting with a spin-up Fermi sea. In this "Fermi polaron" problem, in 2D and in 3D, there is a first-order phase transition between fermionic and bosonic quasiparticle states, and several fundamental open questions could be tackled thanks to our highly efficient algorithm [6]. The internship would consist in preliminary studies for one of the two PhD projects.

References:

[1] R. Rossi, T. Ohgoe, K. Van Houcke, F. Werner, PRL 121, 130405 (2018)
[2] R. Rossi, T. Ohgoe, E. Kozik, N. Prokof'ev, B. Svistunov, K. Van Houcke, F. Werner, PRL 121, 130406 (2018)
[3] K. Van Houcke, F. Werner, E. Kozik, N. Prokofev, B. Svistunov, M. Ku, A. Sommer, L. Cheuk, A. Schirotzek, M. Zwierlein, Nature Phys. 8, 366 (2012)
[4] R. Rossi, PRL **119**, 045701 (2017)
[5] K. Van Houcke, F. Werner, T. Ohgoe, N. Prokof'ev, B. Svistunov, PRB 99, 035140 (2019)
[6] K. Van Houcke, F. Werner, R. Rossi, PRB 101, 045134 (2020)