Probing quantum many–body dynamics with heavy–ion collisions

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The quantum many-body problem is common to all fields aiming at describing complex quantum systems of interacting particles. Examples range from quarks and gluons in a nucleon to macromolecules such as fullerenes. Nuclear systems are another example where up to about 500 nucleons (in the case of actinide collisions) may interact. What make nuclear systems special to test quantum many-body theories is their small size (few fermi) and short "native" time scale (few zeptoseconds) ensuring the complete isolation from external environment, and then, the preservation of quantum coherence during the collision. Heavy-ion collisions are then ideal to investigate fundamental aspects of quantum physics, such as collective motion [1], tunnelling and dissipation [2], coupled channels [3], correlations [4], entanglement [5], etc.

Predicting the outcome of heavy-ion collisions is very challenging as several reaction mechanisms may occur. Ideally, the same theoretical model should be able to describe all the outcomes, e.g., (in)elastic scattering, multi-particle transfer, and fusion. A good starting point is to consider that the particles evolve independently in the mean-field generated by the ensemble of particles. This leads to the well known time-dependent Hartree-Fock (TDHF) theory proposed by Dirac. Recent applications of the TDHF approach and some of its extensions in nuclear physics [6] will be discussed in the talk.

The present microscopic calculations are applied to nuclear collisions around the Coulomb barrier. The fusion mechanism will be discussed first. The fusion between two heavy ions is a complex, highly non linear, and irreversible process. It is strongly coupled to internal structures of the colliding partners resulting from their quantum nature, as well as other reaction mechanisms such as (multi)nucleon transfer. We then investigate how the transfer probabilities evolve with energy. Moreover the path to fusion strongly depends on the mass of the nuclei. For instance, two light nuclei in contact are likely to fuse, whereas this condition is clearly not sufficient for heavy systems which exhibit a fusion hindrance due to the quasi-fission mechanism. Indeed, in the latter, a mass flow between the reactants occurs, leading to a re-separation of more symmetric fragments in the exit channel. A good understanding of the competition between fusion and quasi-fission mechanisms is expected to be of great help to optimize the formation and study of heavy and superheavy nuclei. The quasi-fission mechanism is then also investigated. The predictions of these calculations are compared to experimental data measured at the Heavy-Ion Accelerator Facility of the ANU.

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