The term *ultra-relativistic heavy-ion collision* refers to the interaction between two heavy atomic nuclei (such as lead nuclei) at the energy of at least a few GeV (1 GeV =10^9 eV) per nucleon. The largest heavy-ion accelerator currently operating is the Large Hadron Collider (LHC) at CERN, where lead nuclei are accelerated up to energies of many thousand GeV. In heavy-ion collision experiments, the collision energy is sufficient to create a new form of matter, the Quark-Gluon Plasma (QGP), under laboratory conditions. However, this new state of matter, which forms in the early stage of the ultra-relativistic reaction, cannot be directly detected. The hot and dense but rapidly expanding system of quarks and gluons quickly freezes out into final state hadrons, which we measure in detectors.

How can we obtain information about the system created in the very first, crucial stages of the reaction? The insight into these early stages of the nucleus-nucleus collision can be provided by the analysis of *event-by-event correlations and fluctuations*. In general, correlations and fluctuations characterize the properties of the physical system, and they can be sensitive to the presence of a *phase transition* in nuclear matter. Therefore, they became a standard tool to study the properties of strongly interacting matter at high energies over the years.

Unfortunately, recent theoretical and experimental studies have shown *significant limitations* in the analysis of event-by-event correlations and fluctuations. Most of the commonly used observables (e.g., the correlation coefficient) turned out to be sensitive to event-by-event fluctuations of the volume of the system created in the collision. Hence, even though they provide information on the first stages of the collision, they must be interpreted with extreme caution because this information is *mixed* with trivial volume effects, not related to the early dynamics.

As a remedy to this problem, the analysis of strongly *intensive quantities* Σ and Δ and the technique of *partial correlations* were (independently) introduced into heavy-ion physics. Strongly intensive quantities are constructed in such a way that they are free from the influence of volume fluctuations of the created system. Consequently, they provide far more direct information on how the underlying *sources* produce new particles. Partial correlations, on the other hand, by definition measure the dependence between *physical* variables, with the influence of *confounding* variables removed. Thus, their analysis provides a way to *unfold* the trivial effect of volume fluctuations from the correlation coefficient.

The direct inspirations for the present Project are (1) the first-ever result on the strongly intensive quantity Σ at LHC energies obtained by the Principal Investigator and (2) recent theoretical works on partial correlations in heavy-ion collisions. Encouraged by the first result, the present analysis aims to fully explore the scientific potential of strongly intensive quantities by delivering the first detailed comparative study of these observables at the LHC. This Project will also carry out the first-ever analysis of partial correlations in the ALICE experiment.

The *central goal* of the Project is to provide direct information on primary sources producing particles and correlations between these sources in nuclear collisions at the highest available energies. An extensive experimental analysis is planned to fulfill this task. It will focus on measuring Σ and Δ observables and partial correlations for charged-particle multiplicities for various types of colliding systems and at all collision energies available in the ALICE (A Large Ion Collider Experiment) experiment at LHC. In order to experimentally verify the hypothesis that Σ and Δ observables are *indeed* strongly intensive quantities, the analysis will be carried out using two different methods of *centrality selection* (selection of the number of participating nucleons), provided by ALICE. It will also be performed as a function of the measured size of *system volume fluctuations*. The ALICE detector's excellent experimental capabilities in *particle identification* enable the measurement of all the considered observables, not only for the *summed charged particles,* but also for different types of *identified* hadrons (π mesons, K mesons, protons, or anti-protons). This analysis of identified hadrons will provide new, model-independent insight into the role of the *initial* as well as *resonance* sources of various particles. Moreover, the planned comparison between experimental data and different theoretical models will bring new information on the mechanism of particle production in ultra-relativistic heavy-ion collisions, and its evolution with collision energy and system type.

The new analysis proposed in this Project is an original idea by the Principal Investigator. It will provide valuable new information on the collision dynamics, not burdened by the trivial effects of system volume fluctuations. This constitutes a decisive advantage over the experimental results obtained so far. The proposed extensive comparative study of strongly intensive quantities and partial correlations at the LHC is necessary if a better understanding of the early stage of heavy-ion collisions is ever to be achieved.