Relativistic fluids with spin and polarization in the Quark-Gluon Plasma

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Introduction

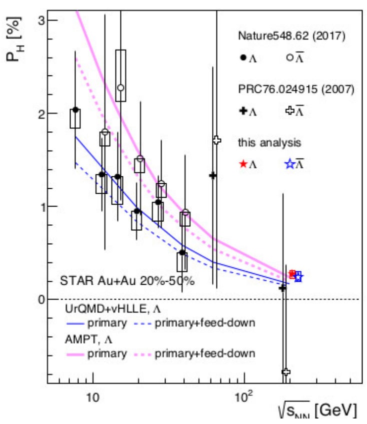

Figure 1: *Comparison between experimental data from STAR [2] compared to theoretical predictions [3].*

Quark-Gluon Plasma (QGP) is a state of matter at such a high temperature (over 2×10^{12} K) that hadrons are melt down into their elementary constituents. Such an extreme state of matter, which was present in the early universe, is nowadays recreated in laboratories by means of nuclear collisions at very high energy, and its study is a very active research field. The QGP appears to be a strongly interacting fluid and its evolution in these collisions is successfully described by relativistic hydrodynamics. Two years ago, the STAR collaboration at RHIC in Brookhaven Laboratories observed the first evidence of a polarization of the QGP in nuclear collisions at finite impact parameter [1]. In particular, it was found that Λ particles stemming from QGP hadronization had a finite global polarization along the direction of the total angular momentum of the plasma, in nice quantitative agreement with theoretical predictions based on relativistic hydrodynamics [3] (see Fig.1). That this phenomenon is driven by local equilibrium rather then by electromagnetic or any other mean field is clearly demonstrated by the almost equal polarization of Λ and its anti-particle $\bar{\Lambda}$. This observation is crucial, being the first clearcut evidence of a quantum effect in relativistic matter and it triggered a lot of theoretical work over the past few years.

Lately, the STAR experiment was able to make more detailed measurements and found that Λ polarization along the beam direction [2] differs from theoretical predictions [4], for the sign is opposite. There is much ongoing theoretical work to explain this and other issues and my Master thesis work was mostly motivated by improving the theoretical description of polarized relativistic fluids.

Master-thesis achievements

The expression of the mean spin of a particle in a relativistic fluid was obtained under some assumptions and approximations; Its exact expression is not known even in the simple case of a fluid in non-trivial global thermodynamic equilibria, that is rotating or uniformly accelerated (corresponding to a fluid in a static gravitational field). In my master thesis I tackled this problem and derived, for non-trivial global equilibria, an exact expression of the so-called *covariant Wigner's function* for free spin $\frac{1}{2}$ fermions, which is the essential step to obtain an exact expression relating polarization and acceleration-vorticity of particles produced by the QGP. This is a crucial advance as, thus far, only finite-order $\hbar$ expansions of the Wigner function were obtained [5]. As a by-product, I was also able to obtain an expression of Wigner's function for massless fermions, which is very important for another popular topic in QGP physics, namely the Chiral Magnetic Effect [6].

The project

The PhD project is a continuation of my studies in the field of relativistic hydrodynamics and kinetic theory with special regard to spin effects. Indeed, the determination of an exact expression of the Wigner function in global equilibria opens the way to several developments and, particularly, I envision these possible steps:

- derive the exact expression of particle polarization and other relevant observables in global equilibrium from the Wigner function;
- extend the solution found in global to local thermodynamic equilibrium and obtain a more accurate expression of polarization;
- implement the improved theoretical formulae in a numerical code based on the hydrodynamical model, in order to obtain predictions for actual heavy ion collisions and compare with data.

Thanks to the results of my Master thesis, I should be able to accomplish the proposed tasks and, hopefully, contribute to explain the features of the measured polarization, as well as predicting new effects.

References

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