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Entanglement, partial set of measurements, and diagonality of the density matrix in the parton model

We analyze the entanglement in the context of high energy QCD. First, in order to provide a firm connection to experimental observables, we define the "entropy of ignorance" which quantifies the entropy associated with ability to perform only a partial set of measurement on a quantum system. For the parton model the entropy of ignorance is equal to the Boltzmann entropy of a classical system of partons. We analyze a calculable model used for describing low x gluons in Color Glass Condensate approach, which has similarities with the parton model of QCD. In this model we calculate the entropy of ignorance in the particle number basis as well as the entanglement entropy of the observable degrees of freedom. We find that the two are similar at high momenta, but differ by a factor of order unity at low momenta. We explicitly demonstrate that that the reduced density matrix of the small x gluons is not diagonal in the particle number basis. We then show that the reduced density matrix can be diagonalized in a quasi-particle basis. Moreover, the matrix elements have the form of Boltzmann weights $\mathrm{diag}(e^{-n\beta\omega})$, $n = 0, 1...$, where n is the number of quasi-particles. At small momenta, $\beta\omega$ is proportional to k/Q_s, demonstrating the apparent thermal behavior of small x gluons at low transverse momentum. We discuss the implication of our results in the context of the future EIC.

Primary author: DUAN, Haowu

Co-authors: Dr KOVNER , Alex; Dr SKOKOV, Vladimir

Presenter: DUAN, Haowu

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