The rapidity profile of the initial energy density in high energy nuclear collisions

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Color Glass Condensate has been identified as the asymptotic limit of quantum chromodynamics (QCD) at very large energies. In this limit hadrons and nuclei can be described as Lorentz-contracted sheets of color charges (in the simplest picture the charges are the valence quarks inside the hadrons) generating a quasi-classical gluon field. There are hints from experimental measurements that large nuclei colliding at RHIC and LHC have reached this asymptotic regime.

Using Color Glass as an effective theory of QCD one can calculate the gluon distribution function of a high energy nucleus. One can then proceed to compute the initial energy density deposited between two such nuclei once they collide. The latter result can serve as the starting point of a calculation describing the evolution of these classical fields toward a thermalized quark gluon plasma. Some work in this direction has been described in previous reports.

However, one basic shortcoming of virtually all Color Glass-based calculations is that they are carried out at the asymptotic point, i.e. for nuclei moving strictly on the light-cone, or in other words with infinite kinetic energy. At RHIC and LHC nuclei are indeed ultra-relativistic (the Lorentz γ-factor is $\approx$100 at top RHIC energies and even larger at LHC). Therefore the asymptotic limit allows for a large number of observables in nuclear collisions to be calculated as long as the rapidity y of the particles involved is much smaller than the rapidity of the colliding nuclei (the beam rapidity). At larger rapidity observables receive corrections if one takes into account that the nuclei are slightly off the light-cone. The corrections grow with $|y|$, and any calculation assuming the asymptotic limit will be unreliable if $|y|$ grows close to the beam rapidity. As an example the initial energy density ε calculated in the asymptotic limit is completely independent of the space-time rapidity η, because the nuclei on the light cone exhibit boost-invariance as a symmetry. But of course causality dictates that ε has to go to zero if $|\eta|$ is larger than the beam rapidity.

In our work we used gluon distribution functions calculated by Lam and Mahlon [1] for nuclei slightly off the light cone in the Color Glass formalism to estimate the rapidity dependence of ε. Our calculation is valid as long as the passing time of the two nuclei $\sim R/\gamma$ is much smaller than the internal time scale of the color glass $\sim 1/Q_s$ where Q_s is also known as the saturation scale. Our results (see Fig. 1 for an example at LHC energies) exhibit approximate boost-invariance around $\eta = 0$ but then predicts a rapid fall off toward beam rapidity. The final result can be conveniently parameterized in terms of Woods-Saxon functions. The parameters for parameterizations are given for Au+Au collisions at RHIC energies and Pb+Pb collisions at LHC energies in our publication [2]. Our result can be used as a starting point for 3+1-dimensional hydrodynamic studies of high energy nuclear collisions.

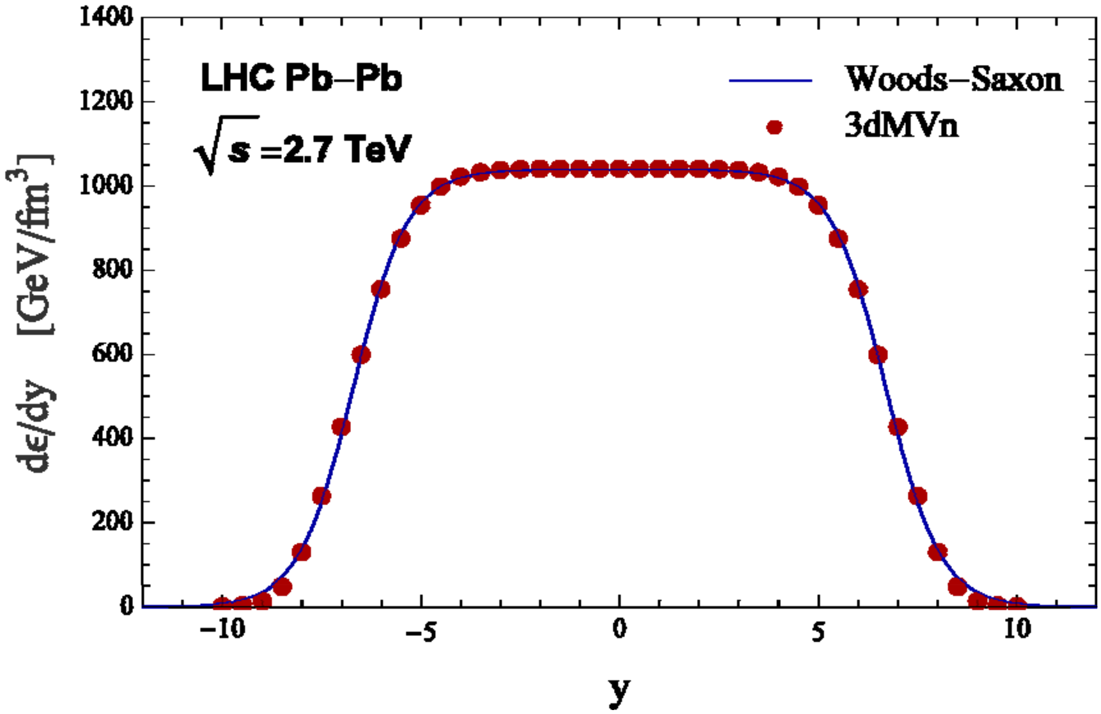

FIG. 1. Initial energy density in the collision of two lead nuclei at LHC as a function of space-time rapidity. The results of the calculation (red circles) can be parameterized by a Woods-Saxon function (blue solid line).

[1] C.S. Lam and G. Mahlon, Phys. Rev. D **62**, 114023 (2000).

[2] S. Ozonder and R.J. Fries, Phys. Rev. C **89**, 034902 (2014).