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Extending the Bjorken Formula to Describe Initial Energy Production at Lower Energies

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The Bjorken formula [1] is very useful for estimating the initial energy density in relativistic heavy ion collisions, once an initial time τ_0 is specified. However, it is well known that the formula is only valid at very high energies [2], where τ_0 is much bigger than the time it takes for the two nuclei to cross each other. Therefore, the Bjorken formula cannot be trusted at lower energies, for example, below $\sqrt{s_{NN}} \sim 50$ GeV for central Au+Au collisions.

Here we extend the Bjorken formula by including the finite crossing time of the two nuclei, which leads to a finite duration time for the initial energy production. We have derived analytical solutions for the energy density as a function of time for several representative duration-time profiles. We also use a multi-phase transport (AMPT) model [3], which treats more realistically the baryon stopping and has been modified to include the finite duration time (as well as the finite longitudinal width) of the initial energy production, and the AMPT results confirm the key features of our analytical solutions. At low energies in comparison with the Bjorken formula, we find [4] that the maximum energy density achieved is much lower while the width of the time evolution of the energy density is much bigger. In addition, it is good to find that the energy density is much less sensitive than the Bjorken formula to the value of the poorly-known formation time τ_0. Furthermore, the extended analytical solutions reduce to the Bjorken formula at high energies. This extension thus provides a general model for the initial energy production of relativistic heavy ion collisions, especially at lower energies such as the RHIC Beam Energy Scan energies.

[1] J.D. Bjorken, Phys. Rev. D 27, 140 (1983).
[2] K. Adcox et al. [PHENIX Collaboration], Nucl. Phys. A 757, 184 (2005).
[3] Z.W. Lin, C.M. Ko, B.A. Li, B. Zhang, and S. Pal, Phys. Rev. C 72, 064901 (2005).
[4] Z.W. Lin, arXiv:1704.08418.

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