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Current Status of Hydrodynamic Modeling from p+p to Heavy Ions

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In recent years, suggestive signatures of collective flow-like behavior have been observed in p+p collisions at the LHC and also in light+heavy-ion collisions. We review hydrodynamic model calculations that reasonably describe the experimentally measured $dN_{\rm ch}/d\eta$ and v_2, v_3, v_4 at $\eta = 0$ in collisions from Pb+Pb down to p+p. Nevertheless, it is still uncertain whether the flow-like correlations in small collisions should be ascribed the same hydrodynamic origin as in heavy+heavy-ion collisions. Resolving this problem requires knowing (1) how a proton should impart its fluctuating shape on hydrodynamic initial data (e.g. ε_2, ε_3), and (2) in what situations hydrodynamics is justified. It turns out the entire non-hydrodynamic behavior of a system is encoded at large orders in the hydrodynamic gradient expansion, whose resummation yields a subset of microscopic system trajectories known as a hydrodynamic attractor. The behavior of trajectories near this attractor define an "off-equilibrium" version of hydrodynamics, whose applicability for small collisions is justified. This provides an answer to (2), but leaves (1), the choice of hydro initial data, as an open issue.

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