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A Covariant Molecular Dynamics Framework for Relativistic N-Body Systems with both scalar and vector potentials

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Since the formation of nuclear clusters, the probing of the nuclear matter equation of state, and the interpretation of hadron correlations at beam energies above 1 GeV all involve strong dynamical correlations and relativistic effects, a covariant
N-body dynamical framework becomes essential for a consistent theoretical description.

In this talk, we will present our recent work on a fully covariant Molecular Dynamics framework that provides a consistent description of relativistic
N-body systems based on the constrained Hamiltonian dynamics formalism. For the first time, we derive relativistic equations of motion incorporating both scalar and vector interactions within a manifestly covariant formulation. This approach resolves several fundamental issues in relativistic many-body dynamics, including the implications of different time-constraint choices, the emergence of the nonrelativistic limit, the frame independence of system evolution, and the distinct dynamical roles of scalar and vector potentials.

We further discuss the relationship of our framework to established models such as RQMD, UrQMD, and JAM, and present illustrative applications to two- and four-body systems, providing new insights into the consistency and physical interpretation of relativistic interactions in a covariant setting. Finally, we outline prospects for implementing this framework in relativistic heavy-ion collision simulations.

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