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3+1D Baryon Transport and Pre-Equilibrium Dynamics in the Fragmentation Region

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The next decade of heavy-ion phenomenology will be significantly shaped by the expansion of experimental reach into far forward kinematics. Upcoming detector upgrades, such as the ALICE FoCal programme and STAR forward calorimetry, require robust theoretical baselines to interpret baryon stopping in regions where standard boost-invariant models fail. We present a fully 3+1D classical transport framework for pre-equilibrium baryon number deposition within the Color Glass Condensate framework. The collision is modelled in the target rest frame as an ultra-relativistic saturated gluon sheet sweeping through a static distribution of collisionless classical coloured particles (Wong quarks). Averaging over the McLerran-Venugopalan ensemble yields the saturation-driven transverse momentum kicks imparted to the target degrees of freedom. This formulation provides analytic and semi-analytic solutions for the phase-space distribution, baryon current, and proper baryon density. By extending previous one-dimensional shockwave models to a realistic 3+1D geometry incorporating Woods-Saxon profiles, we explicitly quantify the competition between longitudinal compression and transverse expansion induced by momentum broadening. We derive a closed analytic expression for the transported baryon rapidity distribution, peaking at $y \simeq \frac{1}{2} \ln(Q_s^2/m_q^2)$. These results establish a mathematically controlled initial state baseline for forward-rapidity hydrodynamics, offering testable quantitative predictions for high-density QCD matter.

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