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Initial-state hard-soft correlations and nuclear modification from saturation physics

High-energy particles are suppressed as they traverse the quark-gluon plasma, but the initial-state contribution to this suppression—or lack thereof—in small systems remains largely unconstrained. We use the saturation-physics-based framework IP-Glasma to predict the nuclear modification factor as a function of centrality in p +Pb, O+O, and Pb+Pb collisions due only to initial-state effects. Tuned only to HERA data, the model accurately predicts the self-normalized multiplicity distributions in p+p, p+O, p+Pb, O+O, and Pb+Pb collisions, the centrality-selected nuclear modification factor in p+Pb collisions, and the anomalous suppression observed in very peripheral Pb+Pb collisions. The model captures the centrality dependence of R_{pPb} and the peripheral Pb+Pb suppression through initial-state effects alone, while the minimum-bias R_{AA} in O+O and Pb+Pb collisions is significantly less suppressed than data, in qualitative agreement with a scenario in which the observed suppression requires final-state energy loss. We show that the hard-soft correlations in IP-Glasma arise from fluctuations in the local saturation scale, which simultaneously drive enhanced production of both soft ($p_T < 3$ GeV) and semi-hard (5–20 GeV) particles, giving a first-principles handle on how centrality selection biases high- p_T observables.

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