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Multi-particle collisions in the hadronic stage: Influence of annihilation and catalysis reactions on proton and deuteron yields

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Multi-particle reactions in the late stages of heavy-ion collisions are demonstrated to be significant for the final deuteron [1] and proton [2] abundances at intermediate to high beam energies. They are realized by employing a stochastic collision criterion in the hadronic transport approach SMASH.

This work sheds light on the puzzle that both final-state coalescence from nucleons and thermal approaches are able to reproduce the deuteron yield. Employing a microscopic treatment [3] of the deuteron production via direct 3<->2 pion and nucleon catalysis reactions reduces substantially the time required for deuterons to reach partial chemical equilibrium with nucleons. Subsequently, the final yield is practically independent from the number of deuterons on the Cooper-Frye hyper-surface. The results are also able to explain the apparent survival of the light nuclei bound by just few MeV at temperatures of more than hundred MeV - the "snowballs in hell" paradox. The deuteron production is studied in AuAu collisions at $\sqrt{s_{\mathrm{NN}}} = 7.7$ GeV as measured by STAR and NA49.

Furthermore, the effect of proton-antiproton annihilation on the (anti-)proton yield is investigated in the late collision stages for a wide energy range of $\sqrt{s_{\mathrm{NN}}} = 17.3\,\mathrm{GeV} - 5.02\,\mathrm{TeV}$ in AuAu/PbPb collisions. The 5-body back-reaction is included for the first time in a full microscopic description in order to fulfill detailed balance for annihilations. This is achieved by accounting for the regeneration of (anti-)protons via $5\pi \to p\bar{p}$. The results show that a back-reaction happens for a fraction of 15-20% of all annihilations. Taking the back-reaction into account results in a regeneration of half of the (anti-)proton yield that is lost due to annihilations at mid-rapidity. The decrease of the proton midrapidity yield reduces the tension of thermal model predictions ("proton anomaly") with the experimental data from LHC and could influence the ongoing efforts to constrain the QCD transport coefficients with Bayesian techniques.

[1]: JS, D. Oliinychenko, J. M. Torres-Rincon & H. Elfner, Phys. Rev. C 104, 034908 (2021)

[2]: O. Garcia-Montero, JS, A. Schäfer, J. M. Torres-Rincon & H. Elfner, arXiv:2107.08812

[3]: D. Oliinychenko, L.-G. Pang, H. Elfner, and V. Koch, Phys. Rev. C 99, 044907 (2019)

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