

Direct Photons from a Hybrid Approach – Exploring the parameter space

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Abstract.

Direct photon spectra are calculated within a transport+hydrodynamics hybrid approach, in which the high-density part of the transport evolution has been replaced by a 3+1-dimensional hydrodynamic calculation. We study the effects of changing the parameters of the two interfaces between the transport- and hydrodynamic descriptions on the resulting direct photon spectra.

1. Introduction

Heavy-ion physics is the principal tool to investigate the phase diagram of strongly interacting matter. Knowledge about the matter created in high-energy nuclear collisions is inferred by studying the remnants of the violent interaction. Since no more direct observation is possible, the experimental observations need to be complemented by theoretical calculations. Unfortunately, first-principle calculations of the whole collision are not feasible, so effective models need to be employed.

Most remnants from heavy-ion collisions are themselves strongly interacting particles, which therefore are mostly emitted in the late stages of the fireball evolution. While they may carry information about the early stages collectively, such as flow patterns, the individual hadron carries only indirect information about the hot and dense phases. Direct photons are well-suited to probe the early stages of a heavy-ion reaction, since due to their small scattering cross-section they leave the reaction zone essentially unscathed. The experimental task of extracting direct photon spectra is challenging, because the decay of hadrons such as the π^0 create a huge background of decay photons. In this article, we investigate a model for direct photon emission [1] with respect to the various parameters used therein.

2. The Model

We use the UrQMD v3.3 transport model [2, 3, 4] and its recent extension to substitute the intermediate high-density stage with an ideal 3+1-dimensional hydrodynamic calculation [5]. The early and late stages are still calculated in the transport model, which implements hadron and string degrees of freedom and uses PYTHIA [6] for scatterings at high momentum transfer. In the intermediate stage, hydrodynamic calculations are performed using three different Equations of State (EoS): A hadron gas EoS (HG-EoS [7]) is used, which has no phase transition, but the same the degrees of freedom as the transport description. A chiral EoS (χ -EoS [8]) which

has a cross-over phase transition to chirally restored and deconfined matter, and a MIT-bag model EoS (BM-EoS [9]) which has a strong first order phase transition with large latent heat to deconfined matter, are also used.

The interfaces between transport and hydrodynamics are the main subject of the present investigations. Transport \rightarrow hydrodynamics: All particles and their momenta are transformed to baryon number-, energy- and momentum densities. In this process, the system is forced into local thermal equilibrium, because in ideal hydrodynamics only perfectly equilibrated matter can be described. The time at which this transition happens t_{start} is, in standard setup, when the initial nuclei have passed through each other. This number depends on the (radii of the) incoming nuclei as well as the incident energy. We investigate the changing of this parameter from $\frac{1}{4}t_0$ to $4t_0$, with t_0 being the standard value. At high energies, this time is too short to allow even for partial thermalization. The minimal time for switching to the hydrodynamic description has been set to $t_{\text{start}} = 0.6$ fm, which is $0.41t_0$ for $Pb + Pb$ -collisions at top SPS-energies ($E_{\text{lab}} = 158$ AGeV) and more than $4t_0$ at $\sqrt{s_{\text{NN}}} = 200$ GeV. Therefore, the latter energy has been omitted from that investigation.

Hydrodynamics \rightarrow transport: Besides the criterion when the transition from hydrodynamics back to transport happens, also the details of this transition can be changed. Usually, the transition happens when the system has diluted below $\varepsilon = 5\varepsilon_0$, where $\varepsilon_0 = 146$ MeV/fm³ is the nuclear ground state energy density. This number is varied between $\varepsilon_{\text{crit}} = 2.5\varepsilon_0$ and $\varepsilon_{\text{crit}} = 10$. The scenario for the transition can either be that the criterion must be met by the part of the system that has the same z -coordinate (along the beam axis), whereafter this slice is transferred to the transport calculation. This is the default **gradual** scenario (for more information the reader is referred to [10]). The other scenario, called **isochronous** scenario, requires the criterion to be met by the whole system, after which it is transferred to the transport calculation instantaneously.

We will change the time for the first transition t_{start} , the critical energy density for the second transition $\varepsilon_{\text{crit}}$ and the scenario for the second transition (gradual vs. isochronous). During each of these changes, the other two parameters are kept at their default values. The calculations are done for central $Pb + Pb$ -collisions ($b < 5$ fm) at $E_{\text{lab}} = 8, 45$ and 158 AGeV and $\sqrt{s_{\text{NN}}} = 200$ AGeV.

3. Results

Figure 1 shows the invariant direct photon yield of calculations with varying start time of the hydrodynamic description. From left to right, the panels show the yield at $0.5 < p_{\perp} < 1.5$ GeV, $1.5 < p_{\perp} < 2.5$ GeV and $2.5 < p_{\perp} < 3.5$ GeV. Each panel shows the yields for $E_{\text{lab}} = 158$ AGeV, scaled by 10 (upper curves), $E_{\text{lab}} = 45$ AGeV (middle curves) and $E_{\text{lab}} = 8$ AGeV, scaled by 1/10 (lower curves). At $E_{\text{lab}} = 8$ AGeV and late switching times $t_0 > 2$ fm, the whole system has an energy density below or close to the threshold for switching back to transport calculations $\varepsilon = 5\varepsilon_0$, so that the hydrodynamic calculation only runs for a very short time. The yield of direct photons is maximal in calculations with $t_{\text{start}} \approx 0.75t_0$ for all systems. In calculations with large t_{start} values, most of the high-density evolution of the system takes place in the transport phase. Here, chemical equilibration is reached only after some time, so that especially the $\pi\rho \rightarrow \gamma\pi$ -channel, which dominates the hadronic sources, is suppressed by the lack of ρ -mesons in the unequilibrated cascade calculation with respect to the equilibrated hydrodynamic calculation.

At the second transition from hydrodynamics to the transport calculation, the system remains in thermal equilibrium. The investigation shown in Figure 2 varies the critical energy density $\varepsilon_{\text{crit}}$ below which the system is described by transport calculations from $\varepsilon_{\text{crit}} = 2\varepsilon_0$, where the applicability of hydrodynamics seems very questionable to $\varepsilon_{\text{crit}} = 10\varepsilon_0$, where the use of a transport calculation might be questioned. We find a slight decrease of the photon spectra as the threshold is raised, consistent with the findings above.

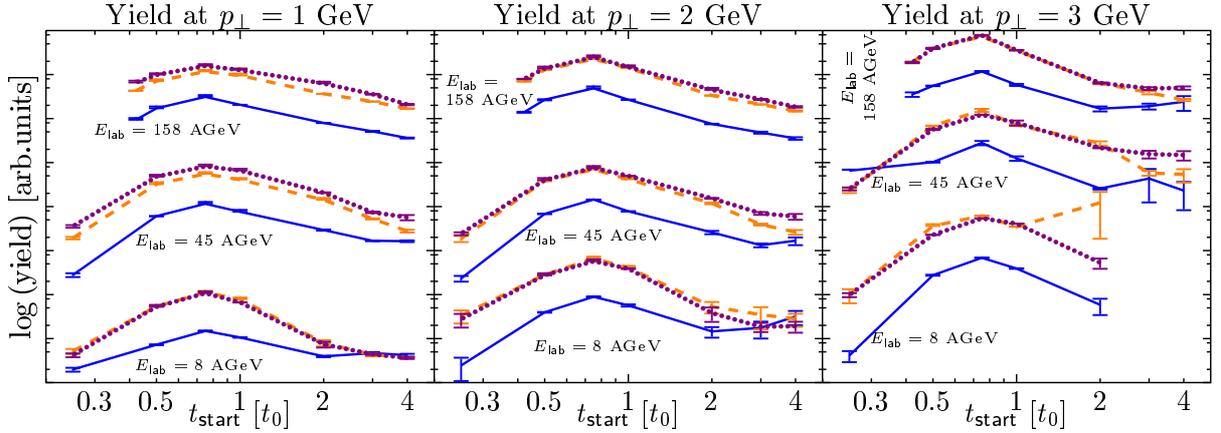


Figure 1. (Color Online) Invariant direct photon yield of calculations with varying start time of the hydrodynamic description. The left panel shows the yield at $0.5 < p_{\perp} < 1.5$ GeV, the middle panel at $1.5 < p_{\perp} < 2.5$ GeV and the right panel shows the yield at $2.5 < p_{\perp} < 3.5$ GeV. Each panel shows the yields for $E_{\text{lab}} = 158$ AGeV, scaled by 10 (upper curves), $E_{\text{lab}} = 45$ AGeV (middle curves) and $E_{\text{lab}} = 8$ AGeV, scaled by 1/10 (lower curves) for HG-EoS calculations (blue solid lines), χ -EoS calculations (orange dashed lines) and BM-EoS calculations (purple dotted lines). The scale is consistent within each panel.

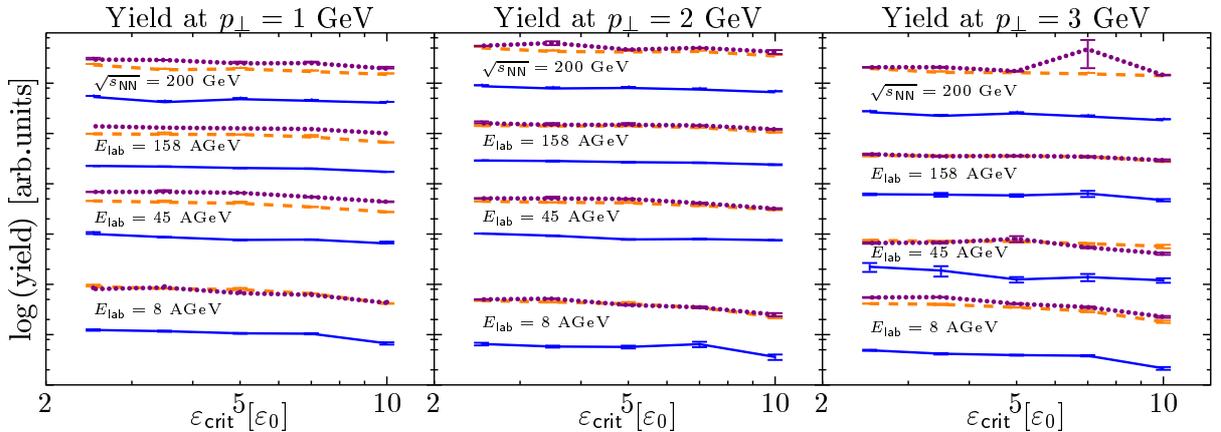


Figure 2. (Color Online) Invariant direct photon yield of calculations with varying critical energy density for the transition from hydrodynamic description to transport description. For explanation of the panels and lines, see the description of Figure 1.

The influence of changing the transition scenario is investigated in Figure 3. The yield in the gradual transition scenario is very similar to the yield in the isochronous transition scenario, albeit a small decrease is visible in most of the calculations. Since in the isochronous transition scenario the fraction of the system calculated with hydrodynamics is larger than in the gradual transition scenario, this is also consistent with the investigations on ϵ_{crit} and t_{start} .

4. Summary

The parameter space of the UrQMD-hybrid model has been explored with respect to direct photon emission. The two major model parameters – the transition time from the initial

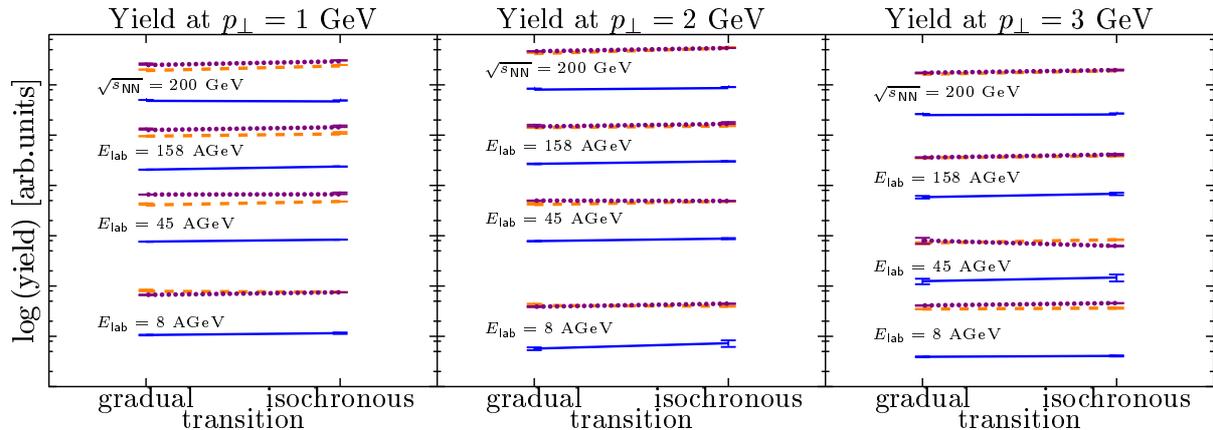


Figure 3. (Color Online) Invariant direct photon yield of calculations with varying the transition scenario for the transition from hydrodynamic description to transport description. For explanation of the panels and lines, see the description of Figure 1.

transport calculation to the hydrodynamic calculation t_{start} and the critical energy density for the transition time from hydrodynamics to the transport calculation ϵ_{crit} – have been varied over a range that includes all reasonable values. In all cases, we find that if a larger part of the evolution is calculated in hydrodynamics, the yield of direct photons increases. Only when the initial transition is done too early (small t_{start}), the direct photon yield is reduced.

The increase of the photon spectra with longer hydrodynamic phase is expected in calculations with a Quark-Gluon-Plasma, which is only present in the hydrodynamic phase and emits more photons than the hadronic phase. In the hadronic phase, the increase is attributed to the higher number of ρ -mesons in the chemically equilibrated hydrodynamic calculation.

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