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**Publication Date**
2000

LBNL-45192

# DILEPTONS FROM TRANSPORT AND HYDRODYNAMICAL MODELS

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## Abstract

Transport and hydrodynamical models used to describe the expansion stage of a heavy-ion collision at the CERN SPS give different dilepton spectrum even if they are tuned to reproduce the observed hadron spectra. To understand the origin of this difference we compare the dilepton emission from transport and hydrodynamical models using similar initial states in both models. We find that the requirement of pion number conservation in a hydrodynamical model does not change the dilepton emission. Also the mass distribution from the transport model indicates faster cooling and longer lifetime of the fireball.

## 1 Introduction

Electromagnetic signals from relativistic heavy-ion collision directly probe the properties of the dense matter created during the collision since their interactions with the surrounding matter are negligible. However, the observed lepton pairs and photons do not originate only at one temperature and density, but the distribution is a complicated integral over the entire space-time history of the system. Therefore, to draw any conclusions of the observed yield, one has to understand the evolution of the system and how it affects dilepton emission.

The evolution of the system is a complicated many-body problem which can not be solved from basic principles but has to be described using phenomenological models instead. Various models based on hydrodynamics and transport theory have been successfully used to describe the hadron data measured in A+A collisions at the CERN SPS energies. However, when they are used to describe dilepton emission in the same collisions, the dilepton yields around invariant mass 500 MeV differ roughly by a factor two [1, 2]. At this mass region the CERES collaboration at CERN has measured a significant excess of dileptons over the estimated background [3]. It has been suggested that this enhancement might be an in medium effect or possibly a precursor of chiral symmetry restoration [4], but before drawing any such conclusions one has to understand why different expansion dynamics can lead to equally large enhancements.

To investigate the effect of expansion dynamics to dilepton production we have compared the dilepton yields from three different models – transport, hydrodynamical model with zero pion chemical potential and hydrodynamical model with conserved pion number.

## 2 The models

To simplify the study of expansion dynamics we have kept the particle content of the system as simple as possible. The only particles included are pions and rho mesons and the only production channel for electron pairs is $\pi\pi$ annihilation. No in-medium modifications of particle properties have been taken into account, but all cross sections, widths etc. are those of free particles.

The transport model we use is the relativistic BUU transport model described in ref. [5] and the hydrodynamical model the 2+1 dimensional non-boost invariant model described in ref. [6]. One of the important differences between these models is that pion number is conserved in the transport model but not in the hydrodynamic model. The pion number conservation leads to non-zero pion chemical potential which is one of the possible causes of the difference in the dilepton yields [7]. To study the effect of non-zero pion chemical potential in the framework of a hydrodynamical expansion we made a new version of the hydrodynamic model where the conserved baryon number is replaced by a conserved pion number[1].

As mentioned the only dilepton production channel we consider is $\pi\pi$ annihilation. The cross section for this process used in the transport description is given in ref. [5] whereas the thermal production rate used in the hydrodynamical description is the one calculated by Gale and Kapusta [8].

We have checked the consistency of our calculations by imposing periodic boundary conditions to our models, initializing the systems in thermal and chemical equilibrium and checking that the equilibrium is maintained. In this

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[1] We define the conserved pion number as $\mathcal{N}_\pi = n_\pi + 2n_\rho$, where $n_\pi$ and $n_\rho$ are the actual number densities of pions and rho-mesons respectively.

case the dilepton emission from all three models is identical and corresponds to the thermal rate at this temperature.

In the simulations of the actual heavy-ion collisions, the initial state of the evolution is chosen to reproduce the observed hadron spectra [1, 5]. However, in the present calculations we use the same initial state for all models: a spherical fireball with a radius of $r = 8$ fm in thermal and chemical equilibrium with no initial flow. The density profile is assumed to be Woods-Saxon with the maximum energy density of $\epsilon = 0.5$ GeV/fm$^3$ which corresponds to a maximum initial temperature of $T = 218$ MeV, pion number density $n_\pi = 0.38$ fm$^{-3}$ and rho number density $n_\rho = 0.20$ fm$^{-3}$. Initially the system contains 560 pions and 260 rhos. The edge of the system is defined by the radius where temperature drops below the decoupling temperature of the hydrodynamic model. This temperature is set to be $T_{dec} = 120$ MeV in both versions of the hydrodynamic model whereas there is no need for a decoupling temperature in the transport model. In the pion number conserving hydro decoupling at $T_{dec} = 120$ MeV leads to an average pion chemical potential on the decoupling surface of $\langle \mu_\pi \rangle = 75$ MeV.

## 3 Results

Since the simulations of the actual heavy-ion collisions are tuned to reproduce the observed hadron spectra, we calculate the pion spectra as well. The resulting $p_t$ spectra of pions is shown in fig. 1. In the hydrodynamic model with zero chemical potential the pion number is not conserved and the number of final pions is smaller than in the other two models. Another difference is that the effective equation of state of the transport model is softer than in the hydrodynamic model. This is manifested in the slope of the $p_t$ spectrum which is steeper for transport calculation than for hydrodynamic calculation with zero chemical potential.

The pion number conserving hydro gives almost similar $p_t$ slope compared to transport. The steeper slope than in zero chemical potential hydro is easily understood. When the system dilutes and pion number is conserved, a larger fraction of energy is stored in the mass of pions than in the case of zero chemical potential. This leads to faster decrease of temperature and the decoupling temperature is reached at an earlier stage of evolution when the flow is less developed.

Fig. 2 depicts the distribution of lepton pairs originating from $\pi\pi$ annihilations during the system evolution. The most striking feature is that the difference between the two hydrodynamical models is tiny. The effect of in-

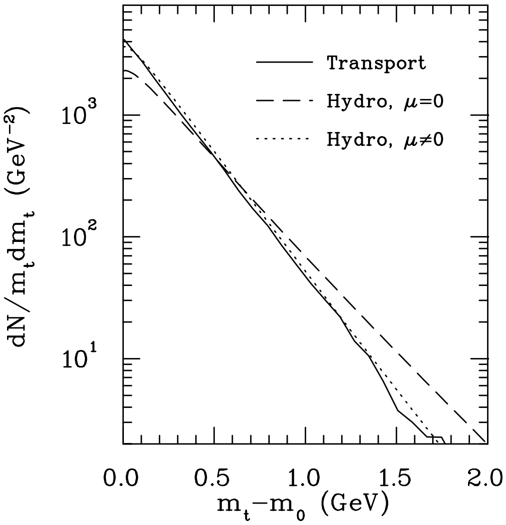

Figure 1: The $p_t$ spectra of pions from transport and hydrodynamical models.

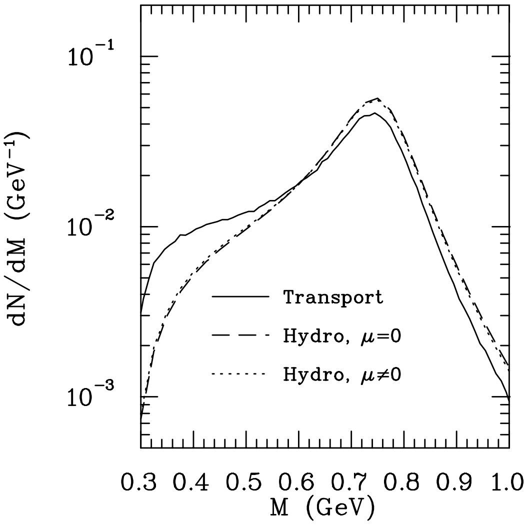

Figure 2: The mass distribution of lepton pairs from $\pi\pi$ annihilation in transport and hydrodynamical models.

creasing chemical potential and thus larger pion density is counterbalanced by the shorter lifetime and faster cooling of the system leading to practically indistinguishable dilepton yields. However, the pion spectra from these two models are different. If the models are required to produce similar pion spectra, the initial state of the model with zero chemical potential should be larger and have lower initial temperature than the pion number conserving model. This difference in the initial state would also lead to different dilepton production.

Since the transport model and the hydrodynamic model lead to similar pion spectra their dilepton yields can be compared without reservations. The difference between these models is similar to that seen in the attempts to reproduce the CERES data. This supports our hypothesis that details of expansion dynamics do have a significant effect on the dilepton production. The shapes of the distributions look like the system in transport description cools faster but lives longer than in hydro. Whether this is the case remains to be investigated in more detail.

We have demonstrated that the effect of the expansion dynamics on dilepton production is visible and that the non-zero pion chemical potential is not the main cause of this effect. At the present stage of the work there are still many open questions like the temperature evolution in the transport description and when and where the dileptons are emitted. It also has to be checked how the distributions change if all the models are required to produce similar pion spectra.

## Acknowledgements

This work was supported by the Director, Office of Science, Office of High Energy and Nuclear Physics, Division of Nuclear Physics, and by the Office of Basic Energy Sciences, Division of Nuclear Sciences, of the U.S. Department of Energy under Contract No. DE-AC03-76SF00098.

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