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Intermediate mass dileptons from secondary Drell-Yan processes*

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Recent reports on enhancements of intermediate and high mass muon pairs produced in heavy ion collisions have attracted much attention. To gain a better understanding of the content of the dilepton continuum, we study Drell-Yan production from secondary hadron interactions in nucleus-nucleus collisions. We show that meson-baryon interactions can be an important source of $m \sim 2$ GeV dileptons. We also discuss the effects of preresonance parton collisions.

1. The model

Measurements of the intermediate [1] and high mass [2] dimuon continuum show that in nucleus-nucleus collisions the yield is enhanced over that expected from conventional sources. We have shown [3] that in addition to the lepton pairs produced by the Drell-Yan mechanism in the initial nucleon-nucleon collisions, the contribution from annihilations of hard valence antiquarks in the produced particles can be important.

A microscopic hadronic transport code, URQMD [4], is employed to obtain a realistic collision spectrum of secondary hadrons. The differential Drell-Yan cross section is computed at leading order (LO) using the standard equation [5]:

$$\frac{\mathrm{d}^2\sigma}{\mathrm{d}m^2\mathrm{d}y}(\mathrm{AB} \to l\bar{l}X) = \frac{4\pi\alpha^2}{9m^2 s}\sum_q e_q^2 \left[q^{\mathrm{A}}(x_{\mathrm{A}}, m^2)\overline{q}^{\mathrm{B}}(x_{\mathrm{B}}, m^2) + \overline{q}^{\mathrm{A}}(x_{\mathrm{A}}, m^2)q^{\mathrm{B}}(x_{\mathrm{B}}, m^2)\right] \ , \quad (1)$$

where $q(x, m^2)$ and $\overline{q}(x, m^2)$ denote the quark and antiquark densities and e_q the charge of the annihilating quarks, $\sqrt{s}$ is the center-of-mass energy of the colliding hadrons, m is the invariant mass of the lepton pair, $x_{\mathrm{A}} = \sqrt{\tau}\ e^{y}$ and $x_{\mathrm{B}} = \sqrt{\tau}\ e^{-y}$ with $\tau = m^2/s$, and y is the dilepton rapidity in the *cms* frame. Since the calculation is performed at leading order only, the result is multiplied by a "K-factor" ($K = 1.5$ for NN collisions).

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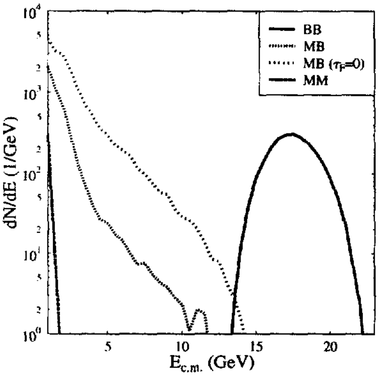

Figure 1. Collision spectrum for Drell-Yan processes in Pb+Pb reactions at $p_{\rm lab}$ = 160 A GeV. Shown are the Glauber-type nucleon-nucleon collisions, meson-meson and meson-baryon (with and without inclusion of preformed hadrons) scatterings.

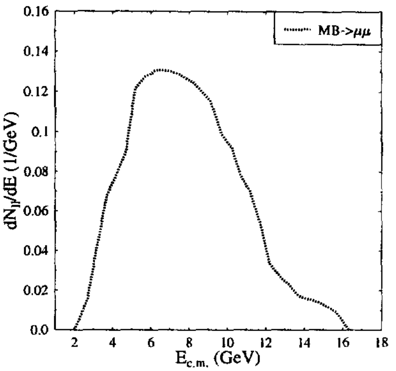

Figure 2. Normalized energy spectrum of meson-baryon collisions in Pb+Pb reactions at $p_{\rm lab}$ = 160 A GeV, weighted with the Drell-Yan production cross section of a m = 2 GeV dilepton.

The dimuon spectra produced in $\pi + A$ reactions are well reproduced by our leading order calculations, scaled by a K factor of 2 [3]. The difference between the K factors required by the proton and by the meson induced reactions might be due to the use of the GRV 92 LO [6] pion set with the GRV 94 LO [7] proton set.

It is clear that in pion-nucleon collisions, *valence* quark-antiquark annihilation can play a significant role in the Drell-Yan process. The pion-nucleon cross sections are consequently higher than the nucleon-nucleon cross sections, especially when $m/\sqrt{s} \gtrsim 0.1$. In heavy-ion collisions, e.g. Pb+Pb reactions at 160 A GeV, the average center of mass energy of the meson-baryon and antibaryon-baryon interactions is around $\sqrt{s} \approx 2$ GeV, certainly less energetic than the primary nucleon-nucleon collisions (see Fig. 1). However, according to our simulation, the average energy of the meson-baryon collisions which produce $m \approx 2$ GeV Drell-Yan pairs is $\sqrt{s} \approx 8$ GeV (see Fig. 2). There is experimental evidence that the Drell-Yan mechanism describes the production of dileptons with $m \geq 2$ GeV in πW interactions at such energies, with a K-factor around 2.4 [8].

The typical scaling of the Drell-Yan cross section with target mass observed in hadron-nucleus collisions, accounted for here, assumes an equal probability for Drell-Yan pair production in each nucleon-nucleon interaction: $\sigma_{\rm pA} = \sigma_0$ A. In addition, in a separate microscopic simulation the meson-baryon, meson-meson and baryon-antibaryon collisions, involving newly produced hadrons, are calculated within the URQMD transport model. In order to conserve energy and momentum, the energy loss of baryons which have already interacted is taken into account in these *secondary* interactions.

For simplicity, the produced hadrons follow straight-line trajectories across the reaction zone without energy loss. The formation time of produced hadrons, on average $\tau_F \approx$ 1 fm/c, is determined by the string fragmentation prescription used in URQMD [4]. Thus, we effectively neglect any possible annihilation of produced partons which have not yet hadronized ("preresonance" scattering). In Sec. 3 we return to this point.

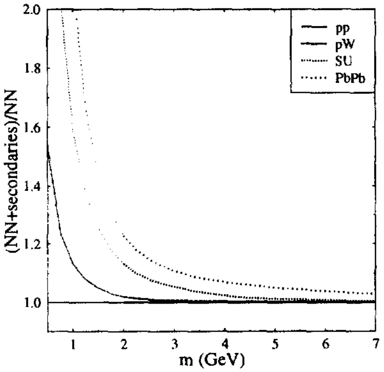

Figure 3. Ratio between the total dilepton mass spectrum and the nucleon-nucleon scattering alone, at $y_{cms} = 0.5$, for different systems: p+W and S+U at 200 *A* GeV, Pb+Pb at 160 *A* GeV.

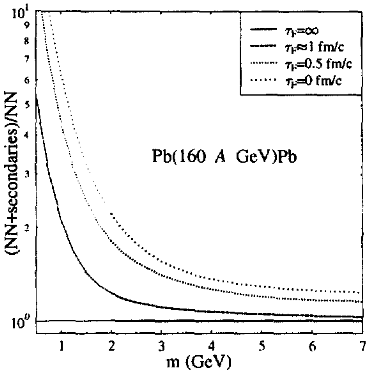

Figure 4. Ratio as in Fig. 3 for Pb+Pb collisions. The calculations correspond to different formation times for the secondary hadrons.

2. Nucleus-nucleus collisions

Figure 3 shows the relative importance of the secondary dilepton production, compared to nucleon-nucleon collisions alone, for different projectile/target combinations. In the mass region around 2 GeV the additional contributions are not negligible in nucleus-nucleus collisions while the increase is less than 5 % in the p+W case. In fact, our calculation including secondary processes is not in conflict with existing pA-data [3].

For masses above 3 GeV, the additional production beyond nucleon-nucleon collisions from our hadronic calculation is less than 10 % in both S+U and Pb+Pb interactions. At masses below 2 GeV, on the contrary, it appears that the contribution from collisions of newly produced particles is important. At masses around 1.5 GeV, an enhancement of 25 % is expected in S+U interactions and 45 % in Pb+Pb interactions. At least part of the observed enhancement of muon pairs at intermediate and low masses [1] might be caused by this previously neglected hadronic source.

The perturbative calculation is definitely unreliable for masses below 1 GeV where a substantial increase in electron pair production in nucleus-nucleus collisions has been observed [9]. To emphasize the theoretical uncertainty of the perturbative calculation for masses below 2 GeV, in Fig. 3 and Fig. 4, we use thinner lines in that region.

The decomposition of the secondary dilepton yield into each channel (meson-baryon, meson-meson, baryon-antibaryon) shows that by far the most important secondary contribution is from meson-baryon interactions.

3. Primordial sources of lepton pairs and formation time

The standard Drell-Yan process corresponds to the interaction of fully formed hadrons. However, it was shown [10] that, during the early stages of the system evolution, partons can scatter and annihilate before they have come on mass-shell. Thus, we postulate the existence of another dilepton source: the annihilation of quarks and antiquarks which are not yet bound in a color-singlet hadron.

To estimate the importance of these "primordial" or "preresonance" $q\bar{q}$ annihilations, we assume that the asymptotic parton distribution functions are also valid for the primordial states. This assumption is distinct from thermal dilepton production where the quark and antiquark are in a thermal environment, in or out of equilibrium, with temperature-dependent parton densities. We thus relax the restriction that the partons can only interact after they have hadronized. This is done very simply in our microscopic cascade calculation by decreasing the formation time of the produced hadrons, τ_F, from the "default" value of around 1 fm/c.

Figure 4 shows that when $\tau_F = 0$, the secondary sources of dileptons become much more important than previously indicated. Indeed, the secondary dilepton yield increases by a factor of ~ 5 at all masses compared to the calculations with the default $\tau_F \approx 1$ fm/c.

In Fig. 4 we have also included a calculation with an intermediate formation time for the produced hadrons, $\tau_F = 0.5$ fm/c, in order to study the sensitivity of the calculations to this (model dependent) parameter. As we might expect, the reduced average formation time leads to an increased dilepton yield due to the larger number of possible hadron-hadron interactions. With this value of the formation time, the enhancement in the range $1.5 < m < 2.5$ GeV shows quite good agreement with the intermediate mass data [1].

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