Dilepton Production in Transport-based Approaches

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We investigate dilepton production in transport-based approaches and show that the baryon couplings of the ρ meson represent the most important ingredient for understanding the measured dilepton spectra. At low energies (of a few GeV), the baryon resonances naturally play a larger role and affect already the vacuum spectra via Dalitz-like contributions, which can be captured well in an on-shell-transport scheme. At higher energies, the baryons mostly affect the in-medium self energy of the ρ, which is harder to tackle in transport models and requires advanced techniques.

1 Introduction

Lepton pairs are known to be an ideal probe for studying phenomena at high densities and temperatures. They are created at all stages of a heavy-ion collision, but unlike hadrons they can escape the hot and dense zone almost undisturbed (since they only interact electromagnetically) and thus can carry genuine in-medium information out to the detector. Dileptons are particularly well-suited to study the in-medium properties of vector mesons, since the latter can directly convert into a virtual photon, and thus a lepton pair [1, 2]. One of the groundbreaking experiments in this field was NA60 at the CERN SPS, which revealed that the ρ spectral function is strongly broadened in the medium. Calculations by Rapp et al. have shown that this collisional broadening is mostly driven by baryonic effects, i.e., the coupling of the ρ meson to baryon resonances (N^*, Δ^*) [3]. In the low-energy regime, the data taken by the DLS detector have puzzled theorists for years and have recently been confirmed and extended by new measurements by the HADES collaboration [4, 5, 6, 7, 8, 9]. At such low energies, it is expected that not only the in-medium properties are determined by baryonic effects, but that already the production mechanism of vector mesons is dominated by the coupling to baryons (even in vacuum).

2 The model: hadronic transport + VMD

Already our previous investigations [10] based on the GiBUU transport model [11] have shown that the baryonic N^* and Δ^* resonances can give important contributions to dilepton spectra at SIS energies, both from pp and AA collisions, via Dalitz-like contributions. This finding was based on the assumption that these resonances decay into a lepton pair exclusively via an intermediate ρ meson (i.e. strict vector-meson dominance). In the transport simulation, the Dalitz decays $R \to e^+e^-N$ are treated as a two-step process, where the first part is an $R \to \rho N$

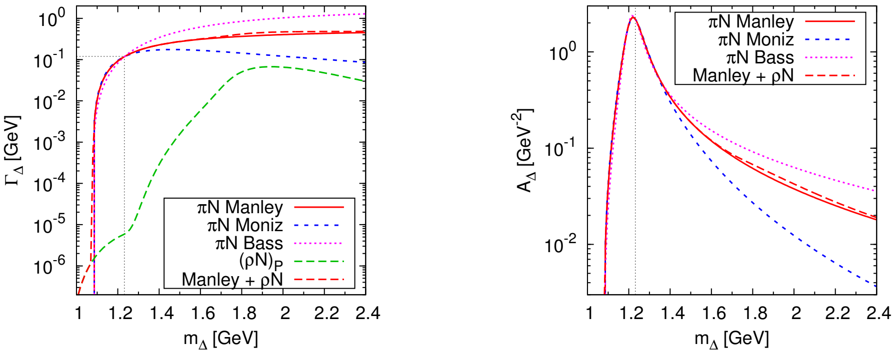

Figure 1: Partial widths for the πN and ρN decay channels (left) and spectral function (right) of the Δ resonance as a function of the off-shell mass.

decay, followed by a subsequent conversion of the ρ into a lepton pair ($\rho \to e^+e^-$). The branching ratios for the $R \to \rho N$ decay are taken from the partial-wave analysis by Manley et al. [12], while the decay width for the second part is calculated under the strict-VMD assumption as $\Gamma_{ee}(m) = \Gamma_0 \cdot (M/m)^3$. For the present study we extend the VMD assumption also to the $\Delta(1232)$ state, whose dilepton contribution has been subject to much controversy recently. Since the Δ is too light to decay into an on-shell ρ meson, it is difficult to determine its coupling to the ρ experimentally, and consequently Manley and other analyses do not find any sign of a $\Delta \to \rho N$ decay. Nevertheless the Δ has a photonic decay mode, which means that also a dilepton Dalitz decay channel must exist. The latter has been claimed to be particularly significant for dilepton spectra at SIS energies [13]. However, this argument was based on the continuation of the photon decay into the time-like region neglecting the involved electromagnetic transition form factor [14]. Unfortunately this form factor is essentially unknown in the time-like region from the experimental point of view. However, it is clear that it can significantly alter the dilepton yield from the Δ (easily by an order of magnitude) [15]. In order to deal with this situation, we choose to apply the assumption of strict VMD not only to the N^* and Δ^* resonances, but also to the Δ itself, assuming a p-wave (i.e. $L = 1$) decay into ρN. Together with the other resonance channels, this results in a consistent model with clear assumptions, which can be tested against experiment. One free parameter that is left to fix in this approach is the on-shell branching ratio of $\Delta \to \rho N$. We use a value of $5 \cdot 10^{-5}$, in order to produce dilepton yields which are roughly equivalent to the radiative decay for small Δ masses and compatible with the HADES data at low energies. Fig. 1 shows the partial decay width into ρN, which is extremely small at the Δ pole mass, but grows significantly when going to larger masses. But even in the very high-mass tail, the additional decay mode has only little influence on the overall width and spectral function of the Δ (even less than the different parametrizations of the πN width).

3 Dilepton spectra from p+p collisions

Fig. 2 shows a comparison of our simulation results for p+p collisions (inside the detector acceptance) to the dilepton mass spectra measured by the HADES collaboration at three different beam energies. Since the mesonic decay channels have not changed with respect to earlier works [10], we concentrate here on the discussion of the baryonic contributions. The Δ is shown in two approaches, a QED-like radiative decay [14] (neglecting the occurring form factor), and a VMD decay $\Delta \to \rho N \to e^+e^-N$. While both give rather similar results at low energies (where the form-factor effects are still small), the differences get larger at higher energies. There the VMD curve develops a clear peak at the ρ mass and a bump around $m_\Delta - m_N \approx 300$ MeV (from the on-shell Δs), while the QED curve is flat and structureless (due to the absence of a form factor). However, both models agree on the fact that the Δ contribution becomes sub-dominant at higher energies and is exceeded by other contributions (in particular the higher resonances N^* and Δ^* become more significant). Thus the data can not distinguish between both models.

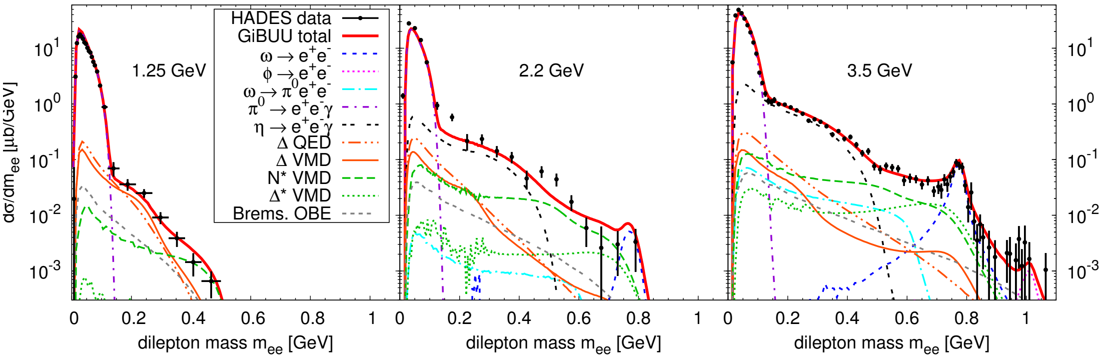

Figure 2: Dilepton mass spectra for pp collisions, in comparison to the data from [4, 5, 6].

4 Dilepton spectra from A+A collisions

Fig. 3 shows our results of dilepton spectra from nucleus-nucleus collisions compared to the HADES data. The light CC system has been measured at two different energies (1 and 2 AGeV) and the heavier ArKCl at the intermediate energy of 1.76 AGeV. The best agreement with data is achieved in the CC system at 2 AGeV, where the spectrum above the pion mass is dominated by the η Dalitz and the baryonic VMD channels. In the 1 AGeV reaction, we see some underestimation at intermediate masses around 300 MeV, despite the inclusion of OBE Bremsstrahlung according to Shyam et al. [16]. Since there are many channels contributing with similar strength here, it is hard to tell where the underestimation originates from. In the medium-size ArKCl system, we see a similar underestimation at intermediate masses and a slight excess in the vector-meson pole region. One may be surprised that a pure (on-shell) transport approach without explicit inclusion of in-medium spectral functions achieves such a good agreement here, but that just shows the importance of Dalitz-like contributions of the baryons, which are captured well by our transport treatment.

5 Conclusions

We have shown that the HADES dilepton data from pp and AA collisions can be described rather well with a combination of a resonance-model-based transport approach with a strict-VMD coupling of the baryons to the em. sector, where a mix of different baryonic resonances contributes to the total dilepton yield. We can not reproduce the dominant contribution of

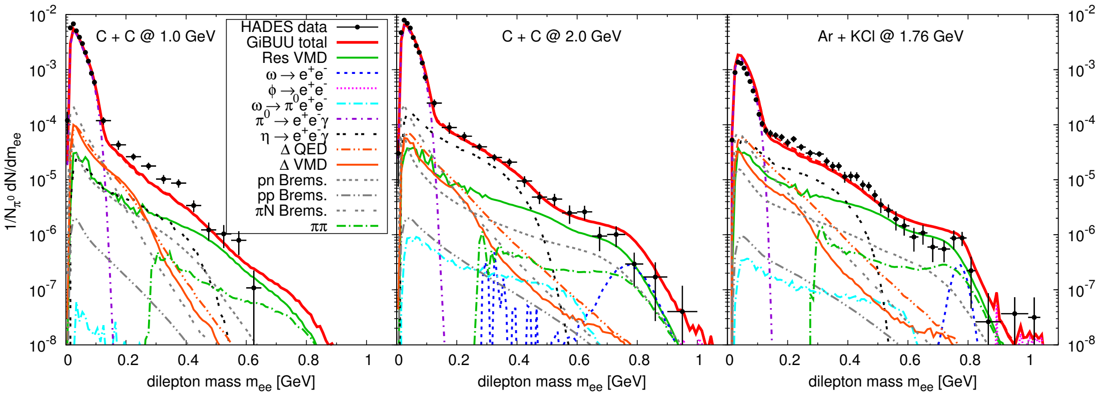

Figure 3: Dilepton mass spectra for AA collisions, in comparison to the data from [7, 8, 9].

the Δ(1232), which was claimed in other models [13]. In order to improve the description of heavy systems and to make the connection to higher energies, a proper dynamic treatment of in-medium spectral functions is required, which may be provided by the so-called “coarse-graining“ approach, which is subject of ongoing investigations [17].

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