Romanian Reports in Physics, Vol. 58, No. 1, P. 63–68, 2006

RESONANCE RESCATTERING AND ABSORPTION IN LOW ENERGY HEAVY ION COLLISIONS

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(Received November 15, 2005)

Abstract. In these proceedings we concentrate on the low energy part of our poster presented at Quark Matter 2005 in Hungary. Transverse and longitudinal momentum spectra of ρ^0 and ω mesons reconstructed from hadron correlations in C+C reactions at 2 AGeV. The rapidity and p_T distributions for reconstructable ρ^0 mesons differs strongly from the primary distribution, while the ω's distributions are only weakly modified. We report on the mass shift of the ρ^0 due to its coupling to the $N^*(1520)$, which is observable in the di-leptonic and $\pi\pi$ decay channel.

Key words: resonance, rescattering, absorption.

Over the last years the exploration of resonance yields and spectra from hadron correlation has attracted a great amount of experimental [1–8] and theoretical attention [9–18].

Recent results from the RHIC accelerator at the BNL in Brookhaven show surprising results, which cannot be explained by statistical model calculations [19, 20]. Also the upcoming results from the HADES collaboration are eagerly awaited to clarify the origin of the in-medium modification of the ρ meson.

For our studies of resonance dynamics in heavy ion collisions we apply the UrQMD model. It is a non-equilibrium transport approach based on the covariant propagation of hadrons and strings. All cross sections are calculated by the principle of detailed balance or are fitted to data where available. The model allows to study the full space time evolution for all hadrons, resonances and their decay products. This permits to explore the emission patterns of the resonances in detail and to gain insight into the origin of the resonances. For further details of the model the reader is referred to [21, 22]. UrQMD has been successfully applied to study light and heavy ion reactions at SIS. Detailed comparisons of UrQMD with a large body of experimental data at SIS energies can be found in [23].

The results shown in this proceedings are obtained by simulations of more than $8 \cdot 10^6$ events of min.bias C+C interactions at 2 AGeV. The statistical errors in the calculation are therefore smaller than 5% and will not be shown separately.

In order to decide whether a resonance is counted as reconstructable or not, we follow the decay products of each decaying resonance (the daughter particles). If any of the daughter hadrons rescatters, the signal of this resonance is lost. If the daughter particles do not rescatter in the further evolution of the system, the resonance is counted as ‘reconstructable’. Note that all decaying resonances are dubbed with the term ‘all decayed’. These resonances are reconstructable by an invariant mass analysis of di-leptons (after multiplication with the respective branching ratio $\Gamma(R \to e^+e^-)$). The advantage of this method is that it allows to trace back the origin of each individual resonance to study their spatial and temporal emission pattern. Even more it enables one to study the production process of the finally observed resonance itself, shedding light on the origin of mass modifications.

Resonances that have electromagnetic and hadronic decay channels allow for a thorough investigation of the dynamics and lifetime of the hadronic medium. That is because the leptonic decay channel carries information from the early stages of the reaction, since the leptons can leave the dense regions undisturbed, while the hadronic decay channel carries information from the late stages (near kinetic decoupling) of the evolution.

Fig. 1 depicts the rapidity distributions of the meson resonances for min.bias C+C interactions at 2 AGeV. The full symbols display those ρ^0 (circles) and ω (squares) resonances which are reconstructable via hadron correlations. This means that the daughter particles do not interact after the decay of the resonance. The open symbols show the spectra for all decayed ρ^0 and ω resonances. This can be interpreted as the spectrum which can be measured via a di-leptonic decay, not taking into account any interferences of the ρ and the ω. In the case of the ρ^0 one observes a drastic reduction of the observable yield at midrapidity from 3.5% (in

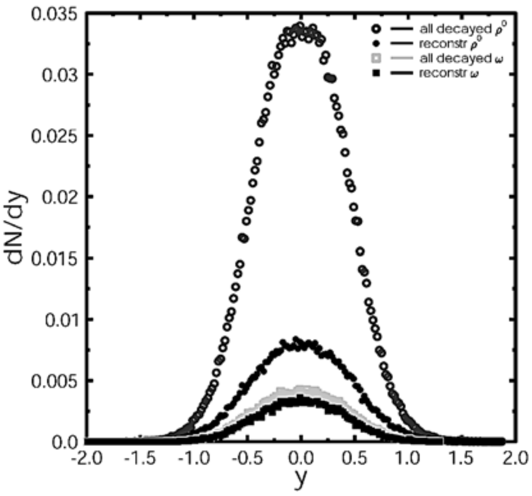

Fig. 1 – Rapidity distribution of the decayed mesons for min. bias C+C reactions at 2 AGeV. The open circles/squares show the ρ^0_{770} ’s / ω’s which can be reconstructed in the pion channel, full circles depict all decayed ρ^0’s / ω’s. A strong suppression of in hadron correlations reconstructable resonances compared to those reconstructable via leptonic decays (indicated as ’all decayed’) is visible for the ρ^0 mesons, whereas the spectrum for the ω meson is only weakly altered.

the di-lepton channel) to 0.8% in the hadronic channel. In contrast, the ω meson is only slightly altered when the reconstruction probabilities in both channels are compared. This can be traced back to the much longer lifetime of the ω compared to the ρ. Most of the ω's will leave the interaction zone before they decay, thus reducing the possibility of the rescattering of the daughters.

If this interpretation is valid, one expects a strong transverse momentum $(p_T = \sqrt{p_x^2 + p_y^2})$ dependence of the suppression pattern. One would expect a larger modification of short lived resonances at low transverse momentum. The spectrum at higher transverse momenta will only be slightly altered, because high p_T-resonances are more likely to escape from the interaction region before they decay. As shown in Fig. 2 the ρ^0_{770} meson is suppressed, especially at low p_T, in line with our expectations from the rescattering picture. Only at very low transverse momenta, the ω_{782} is weakly suppressed. It should be noted that a similar behaviour was also found experimentally for larger systems at higher energies [7].

Fig. 3 depicts the ρ^0/π^- ratio as a function of p_T. One can see a strong suppression of the ρ^0/π^- ratio at low p_T for the reconstructable resonances, which vanishes at high p_T. This also supports the rescattering scenario, since high p_T pions and ρ^0's leave the medium directly and therefore do not rescatter.

Let us finally discuss, one of the most interesting effects, the modification of the mass spectrum of the ρ^0 meson. It has been discussed earlier for example in [24–26]. The mass distribution of the ρ^0 in min.bias C+C reaction at 2 AGeV is shown in Fig. 4. Open circles depict all decayed ρ's (this is similar to the di-leptons

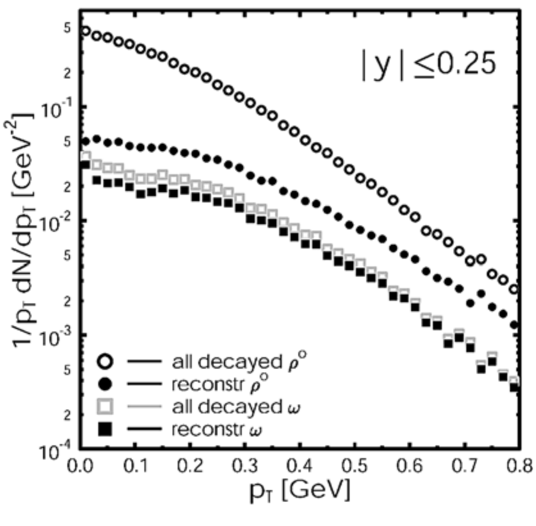

Fig. 2 – Transverse momentum distributions of ρ^0 mesons (circles) and ω_{770} mesons (squares) for min. bias C+C reactions at 2 AGeV at midrapidity ($|y| \leq 0.25$). Circles depict ρ^0 mesons, squares depict ω mesons. Open symbols show all decayed resonances, whereas full symbols show those actually reconstructable via hadron correlations. There is a huge modification for the ρ^0 meson spectrum at low p_T, whereas the high p_T part is modified less (factor of 4–5 less compared to the low p_T part). There is only a very slight modification visible for the the ω meson.

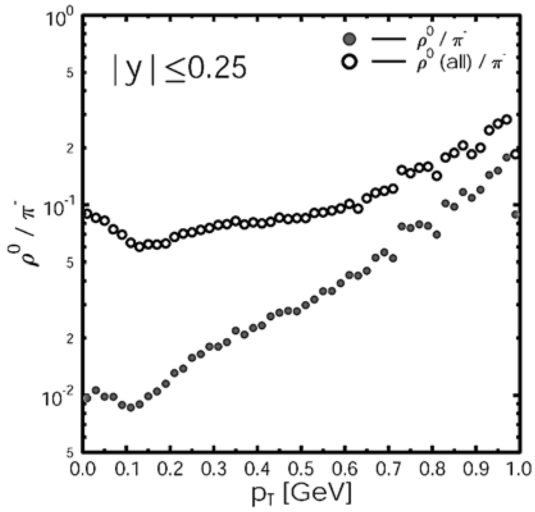

Fig. 3 – The ρ^0/π^- ratio as a function of transverse momentum for min. bias C+C reactions at 2 AGeV at midrapidity ($|y| \le 0.25$). Full circles depict the via hadron correlations reconstructable ρ^0's over pions, whereas the blue circles depict all decayed ρ^0's over pions. It is evident that there is less suppression at higher transverse momentum.

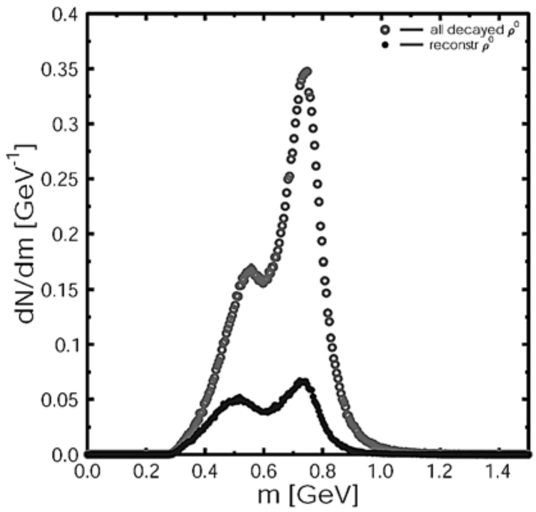

Fig. 4 – Mass distribution for ρ^0 mesons for min. bias C+C reaction at 2 AGeV. The peak around 500 MeV is due to a strong contribution from $N^*_{1520} \to p + \rho$ which amounts to 75% for masses below 600 MeV.

invariant mass distribution multiplied by the branching ratio and the vector meson dominance factor of $1/m^3$), while the ρ's reconstructable in ππ correlations are shown as full circles.

One observes a clear double peak structure in both distributions, with maxima at the ρ pole mass (770 MeV) and around 500 to 600 MeV. Usually an enhancement of the ρ spectral function in this mass region has been attributed to strong in-medium modifications, due to finite densities and temperatures. However, in the present calculation, we do not make explicit use of any in-medium modification, but only include the coupling of the ρ meson to pions and baryons via the employed cross sections calculated from detailed balance.

A detailed analysis shows that the low mass peak is due to the decay chain $N^*_{1520} \to p + \rho^0$ which contributes to 75% to the reconstructable ρ mass spectrum below 600 MeV. Without in-medium modifications, this decay process restricts the mass of the ρ to $m_\rho \leq m_{N^*_{1520}} - m_p \sim 580$ MeV and thus feeds strongly into the low invariant mass region of the ρ. Above 600 MeV, ρ's are mostly produced from $\pi\pi \to \rho$. It seems that a dramatic modification of the ρ spectral function is mostly due to the decay kinematics of the production channel of the ρ. However, on top of these kinematic effects additional modifications of the ρ mass spectrum might occur.

In summary, we have explored ρ and ω production in C+C interactions at 2 AGeV. The present calculation shows a strong difference (factor 5) between the yields observable in the di-lepton and hadron channel. This can be understood due to a rescattering of the resonance decay products, making the resonance undetectable for the experiment. At midrapidity $8 \cdot 10^{-3}$ ρ^0's per event can be reconstructed from the pion correlations. We predict a strong transverse momentum dependence of the ρ suppression pattern leading to an apparent heat-up of the ρ's observed in the hadronic channel compared to the di-lepton channel. Finally, we have pointed out that the mass spectrum of the reconstructable ρ's shows a strong double peak structure. This second peak around an invariant mass of 500 MeV is due to ρ's from the decay of the N^* (1520) which feeds directly in to the ρ mass region below 580 MeV. Our prediction are a complimentary approach to the di-lepton measurements underway at HADES/GSI.

Acknowledgements. The authors thank GSI, DFG and BMBF for support. We also thank the organisers of the Quark Matter 2005 for a great conference. The computational resources have been provided by the Center for Scientific Computing in Frankfurt.

REFERENCES

1. C. Markert [STAR Collaboration], J. Phys. G **30** (2004) S1313 [arXiv:nucl-ex/0404003].
2. C. Markert [STAR Collaboration], arXiv:nucl-ex/0308029.
3. C. Markert [STAR Collaboration], J. Phys. G **28** (2002) 1753 [arXiv:nucl-ex/0308028].
4. P. Fachini [STAR Collaboration], J. Phys. G **30** (2004) S565 [arXiv:nucl-ex/0305034].
5. P. Fachini, Acta Phys. Polon. B **35** (2004) 183 [arXiv:nucl-ex/0311023].
6. P. Fachini, J. Phys. G **30** (2004) S735 [arXiv:nucl-ex/0403026].
7. J. Adams *et al.* [STAR Collaboration], arXiv:nucl-ex/0412019.
8. S. S. Adler *et al.* [PHENIX Collaboration], arXiv:nucl-ex/0409015.
9. S. C. Johnson, B. V. Jacak and A. Drees, Eur. Phys. J. C **18** (2001) 645 [arXiv:nucl-th/9909075].
10. M. Bleicher and J. Aichelin, Phys. Lett. B **530** (2002) 81 [arXiv:hep-ph/0201123].
11. G. Torrieri and J. Rafelski, Phys. Rev. C **68** (2003) 034912 [arXiv:nucl-th/0212091].
12. M. Bleicher, Nucl. Phys. A **715** (2003) 85 [arXiv:hep-ph/0212378].
13. M. Bleicher and H. Stocker, J. Phys. G **30** (2004) S111 [arXiv:hep-ph/0312278].

14. G. Torrieri, S. Steinke, W. Broniowski, W. Florkowski, J. Letessier and J. Rafelski, arXiv:nucl-th/0404083.
15. S. Vogel and M. Bleicher, arXiv:nucl-th/0505027.
16. S. Soff *et al.*, J. Phys. G **27** (2001) 449 [arXiv:nucl-th/0010103].
17. G. Torrieri and J. Rafelski, Phys. Lett. B **509** (2001) 239 [arXiv:hep-ph/0103149].
18. G. Torrieri and J. Rafelski, J. Phys. G **28** (2002) 1911 [arXiv:hep-ph/0112195].
19. P. Braun-Munzinger, D. Magestro, K. Redlich and J. Stachel, Phys. Lett. B **518** (2001) 41 [arXiv:hep-ph/0105229].
20. K. Schweda, Talk given at the Quark Matter 2004.
21. S. A. Bass *et al.*, Prog. Part. Nucl. Phys. **41** (1998) 225 [arXiv:nucl-th/9803035].
22. M. Bleicher *et al.*, J. Phys. G **25** (1999) 1859 [arXiv:hep-ph/9909407].
23. C. Sturm *et al.* [KAOS Collaboration], Phys. Rev. Lett. **86** (2001) 39 [arXiv:nucl-ex/0011001].
24. G. E. Brown and M. Rho, Phys. Rev. Lett. **66** (1991) 2720.
25. R. Rapp and C. Gale, Phys. Rev. C **60** (1999) 024903 [arXiv:hep-ph/9902268].
26. W. Cassing, E. L. Bratkovskaya, R. Rapp and J. Wambach, Phys. Rev. C **57** (1998) 916 [arXiv:nucl-th/9708020].