QCD Sum Rules for ρ Meson in Vacuum and in-Medium ◇

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Vector mesons are expected to change their properties in a nuclear medium, for instance the mass shift related to chiral symmetry restoration and the broadening of the width due to interactions with nucleons and mesons. Theoretical constraints to study this issue are provided by in-medium QCD sum rules, are a framework which relates QCD parameters (e.g. condensates) to hadronic structure constants. In the actual calculations correlation functions establish the bridge between QCD and phenomenology.

In the present work QCD sum rules for the lowest moments of ρ meson spectral functions, both in vacuum and in medium, are constructed. The sum rule analysis for the first two spectral moments has the advantage that unphysical parameters such as the Borel mass and uncertain higher order condensates are eliminated. Quantitatively accurate statement can therefore be made. Identifying the scale s_0, which delineates resonances and continuum region (see Fig. 1), with the chiral symmetry breaking scale, $\sqrt{s_0} = 4\pi f_\pi$ (the chiral gap), we can test the pattern of chiral symmetry restoration and hypotheses such as Brown-Rho (BR) scaling.

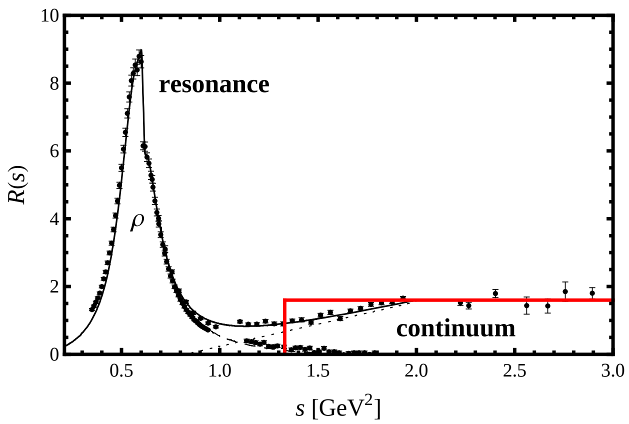

Fig. 1: Vector-isovector spectral function in vacuum showing the ρ resonance and continuum parts as described in the text and compared to $e^+e^- \to \pi^+\pi^-$ (ρ resonance region) and $e^+e^- \to n\pi$ data with n even.

For the vacuum case the identification $\sqrt{s_0} = 4\pi f_\pi$ immediately establishes fundamental current algebra relations such as the KSRF relation. We solve the sum rule equations for the two lowest moments of ρ meson spectrum with its realistic width and find $\sqrt{s_0} = 1.14 \pm 0.01$ GeV. This hypothesis appears to be still working quantitatively. The average mass defined as the square root of the ratio between first and the zeroth moment, is obtained as $\bar{m} = 0.78 \pm 0.01$ GeV, consistent with the physical ρ meson mass.

Then we investigate the ρ meson in the medium at normal nuclear matter density ($\rho_0 = 0.17$ fm^{-3}) and zero temperature. Extending the chiral scale hypothesis to the in-medium case, $\sqrt{s_0^*} = 4\pi f_\pi^*$, we apply the same approach as in vacuum to spectral functions at finite density. Fig. 2 shows examples illustrating that the strong broadening of the in-medium spectral functions does not permit identifying an “in-medium mass” by first inspection. However, defining an average in-medium mass, $\bar{m}^*$, in terms of the ratio of the first two spectral moments is nonetheless a valid procedure.

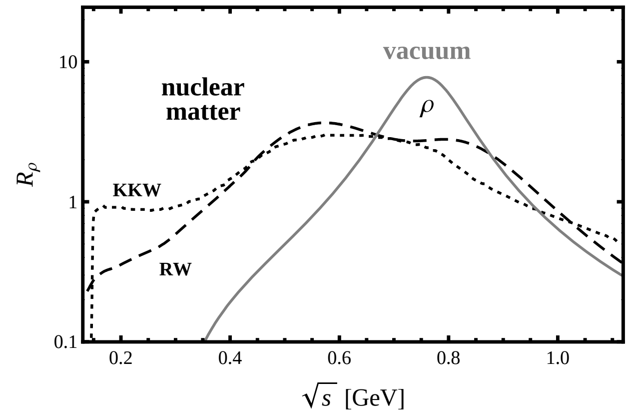

Fig. 2: In-medium vector isovector spectral functions at nuclear matter density, $\rho_0 = 0.17$ fm^{-3}, taken from Refs. [2] (KKW) and [3] (RW). The ρ meson spectrum in vacuum is also shown for comparison.

The in-medium QCD sum rule analysis for the lowest two moments makes the “mass shift” versus “broadening” issue meaningful even for broad spectral distributions such as that of the ρ meson at nuclear matter density. As a result, the KKW spectral function reproduces the BR scaling, $\bar{m}^*/\bar{m} \simeq f_\pi^*/f_\pi \simeq 0.86$, while the RW spectrum exhibits solely broadening, with almost no in-medium shift of the ratio of the moments.

Given spectral functions which consistently satisfy the sum rules for the zeroth and first moments, one can also turn to the second moment in order to deduce constraints for the four-quark condensate both in vacuum and in-medium. When performing the consistency analysis including the sum rule for the second moment, it turns out in all cases that the corresponding correction is required to be much larger than the expected value for a factorized four-quark condensate. One concludes that the factorization approximation is unrealistic under any circumstances.

References

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