COMPREHENSIVE PARAMETERIZATION OF THE $\rho$-MESON SPECTRAL FUNCTION IN HOT AND DENSE MATTER

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INTRODUCTION
OUTLINE

• Elementary particles in the quark-gluon plasma
• Quark-Gluon plasma in heavy ion collisions
• $\rho$-mesons to probe quark-gluon plasma through dilepton pairs
• $\rho$-meson spectral function in hot and dense matter
• Parameterization of $\rho$-meson spectral function
INTRODUCTION TO THE STANDARD MODEL

• Protons and neutrons are collectively called nucleons
• Nucleons are composed of 3 quarks
• The standard model describes all indivisible subatomic particles
STATES OF MATTER

- Solid
- Liquid
- Gas
- Electromagnetic Plasma
- Hadronic Plasma
- Quark-Gluon Plasma

Temperature
STATES OF MATTER

Gas

- When the average thermal energy of a substance is hot enough to separate electrons from their atomic nuclei

Electromagnetic Plasma

- When the average thermal energy of a substance is hot enough to dissolve nuclei into protons, neutrons, and other hadrons

Hadronic Plasma

- When the average thermal energy of a substance is hot enough to break down hadrons into deconfined quarks and gluons

Quark-Gluon Plasma
THE NEUTRAL $\rho$-MESON AND ITS PROPERTIES

• A meson is a particle composed of two quarks (a quark and an antiquark)
• There are 2 ways to construct a neutral $\rho$-meson
• This particle has possibilities for decay: a pair of dileptons or a pair of pions
THE DECAY OF THE $\rho$-MESON

- Due to the strong nuclear force interaction, pion pion decay is the more probable outcome as opposed to the dilepton decay.
UTILITY OF DILEPTON PAIRS

- Can be analyzed during heavy ion collisions
- Can probe the spectral properties of hot, dense media, particularly during quark deconfinement and mass degeneration
- Doesn't interact using the strong nuclear force
THE SPECTRAL FUNCTION AND THE PURPOSE OF ITS TERMS
HEAVY ION COLLISIONS AND $\rho$ DECVAYS

Au + Au

QGP ?!

Hadron Gas

"Freeze Out"
DILEPTON PAIR PRODUCTION RATE

\[ \frac{dN_{ee}}{d^4x\,d^4q} = \text{constant} \times \frac{1}{M^2} \times e^{-q_0/T} \times Im[D_\rho(M, q, T)] \]

- This the production rate per volume per time per 4-momentum
- Shows the relationship between the production of dilepton pairs and the propagation of the ρ-mesons that the pairs decayed from
THE PROPAGATOR OF THE $\rho$-MESON IN HOT MATTER

$$D_\rho(M, q, T) = \frac{1}{M^2 - \left(m_\rho^{(0)}\right)^2 - \Sigma_{\rho\pi\pi}(M, q, T) - \Sigma_{\rho M}(M, q, T')}$$
MODIFIED VACUUM TERM

\[ \Sigma_{\rho\pi\pi}(M, q, T) = -aM - iM\Gamma_{\rho}(M, q, T) \]

- Describes the properties of the \( \rho \)-meson in the vacuum due to the two pion decay
- \( a \) characterizes the mass modification
- \( \Gamma_{\rho} = \frac{g_{\rho}^2}{6\pi} \times \frac{M}{8} \times \left( \frac{M}{0.8} \right)^4 \times \left( 1 + \frac{2c_{\pi}}{q_0} \frac{q_0}{e^{2T} - 1} \right) \) is the vacuum width for the decay into two pions
- \( g_{\rho} \) is the coupling constant
RHO MESON INTERACTIONS WITH MESONIC MATTER

\[ \Sigma_{\rho M}(M, q, T) = -i m_{\rho} \left( \frac{T}{0.15} \right)^{\alpha_I} (\Gamma_1 + \Gamma_2) + \text{Re}(\Sigma_{\rho M}) \]

- \( \Gamma_1 = \Gamma_0 \times \left( \frac{M+0.1}{1.3} \right)^5 \left( \frac{\Lambda_1^2 + m_{\rho}^2}{\Lambda_1^2 + M^2} \right)^8 \)

- \( \Gamma_2 = \left[ b(M) \times \left( \frac{q}{0.4} \right)^3 + (1 - b(M)) \left( \frac{q}{0.15} \right)^2 \right] \left( \frac{\Lambda_2^2 + m_{\rho}^2}{\Lambda_2^2 + q^2} \right)^2 \times \frac{0.001}{1+25*M^6} \)

- \( b(M) = \frac{1}{e^{(M-0.2)/0.1}+1} \)

- \( \text{Re}(\Sigma_{\rho M}) = \begin{cases} M < 0.75, & (-0.01)c_m m_{\rho} \left( \frac{T}{0.15} \right)^{\alpha_R} ; \\ 0.75 < M < 1.2, & c_m m_{\rho} \left( \frac{T}{0.15} \right)^{\alpha_R} \left( \frac{M-0.85}{10} \right) ; \\ 1.2 < M, & (0.035) c_m m_{\rho} \left( \frac{T}{0.15} \right)^{\alpha_R} \end{cases} \)

- This term describes how the \( \rho \)-meson interacts with other mesons
DATA COMPARISON
MOMENTUM DEPENDENT PARAMETERIZATION

- Real Vacuum Coefficient
- Real Temperature Exponent
- Imaginary Temperature Exponent
- Primary Decay Width Coefficient

\[ c_m = 2.0166 - 2.179 \times q \]
\[ \alpha_R = \begin{cases} q < 0.5, & 5.02569 \left(1 - \frac{q}{0.5}\right); \\ q \geq 0.5, & 0 \end{cases} \]
\[ \alpha_I = \begin{cases} q \geq 0.5, & 3.93722; \\ q < 0.5, & 10.3502 - \frac{10.3502 - 3.93722}{0.5} \times q \end{cases} \]
\[ \Lambda_1 = 1.235 + e^{1.3907 - 2.8q} \]
\[ \Lambda_2 = 0.68997 + 78498 \times \frac{q^{0.000015 - 18.584 + 0.0538}}{(q^{-1.4774 - 24.2505 + 0.0538})^2 + 0.17} \]
\[ \Gamma_0 = 0.19 + 218309 \times \frac{1 - q^{8.121 \times 10^{-6}}}{(1 - q^{-3.086})^2 + 0.4533^2} + 0.2005 \times q^2 \]
SELF-ENERGY IN MESONIC MATTER

Temperature = 0.15 GeV
3-Momentum = 0.3 GeV
IN-MEDIUM PROPAGATION

• Comparison of the parameterization with the theoretical data for the Spectral Function

Temperature=0.15 GeV
3-Momentum=0.3 GeV
COMPARISON OF THE PARAMETERIZATION WITH THE CALCULATED DILEPTON RATE

Temperature=0.15 GeV, 3-Momentum=0.3 GeV

Temperature=0.18 GeV, 3-Momentum=0.1 GeV

Data — Rate

Data — Rate
IMPLICATIONS FOR THE FUTURE
FUTURE PLANS

1. Complete the 3-Momentum dependence of the baryonic interactions

2. Complete the baryon density dependence of the spectral function

3. Parameterized spectral function can be used to analyze the properties of the quark-gluon plasma
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