COMPREHENSIVE PARAMETERIZATION OF THE ρ-MESON SPECTRAL FUNCTION IN HOT AND DENSE MATTER

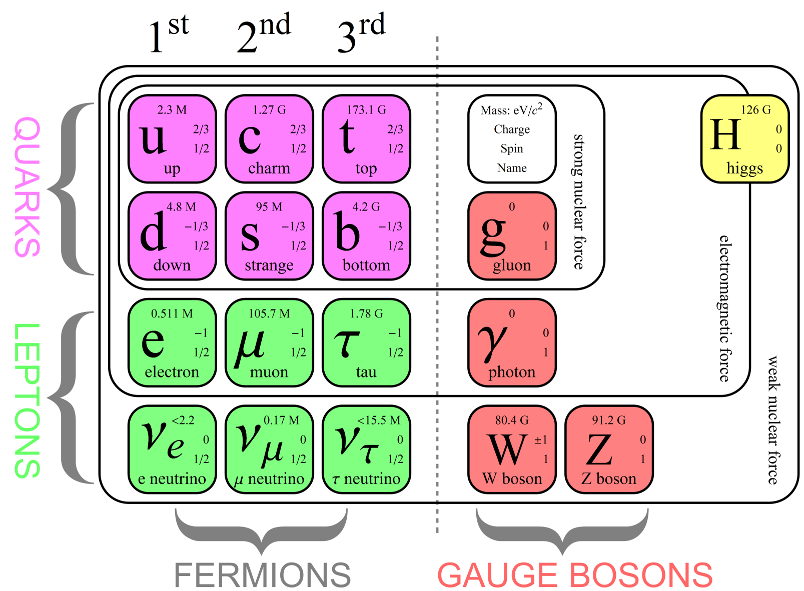
By Thomas Onyango
Ralf Rapp

INTRODUCTION

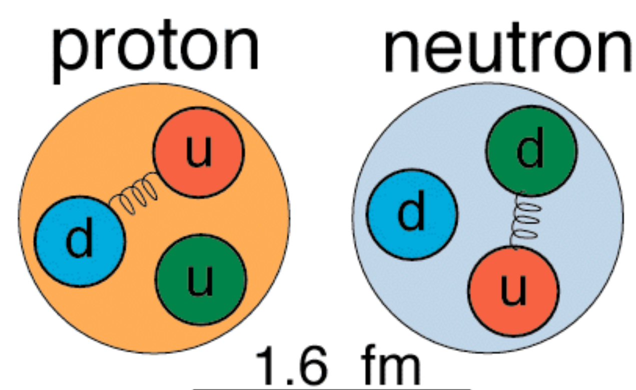
OUTLINE

- Elementary particles in the quark-gluon plasma
- Quark-Gluon plasma in heavy ion collisions
- ρ-mesons to probe quark-gluon plasma through dilepton pairs
- ρ-meson spectral function in hot and dense matter
- Parameterization of ρ-meson spectral function

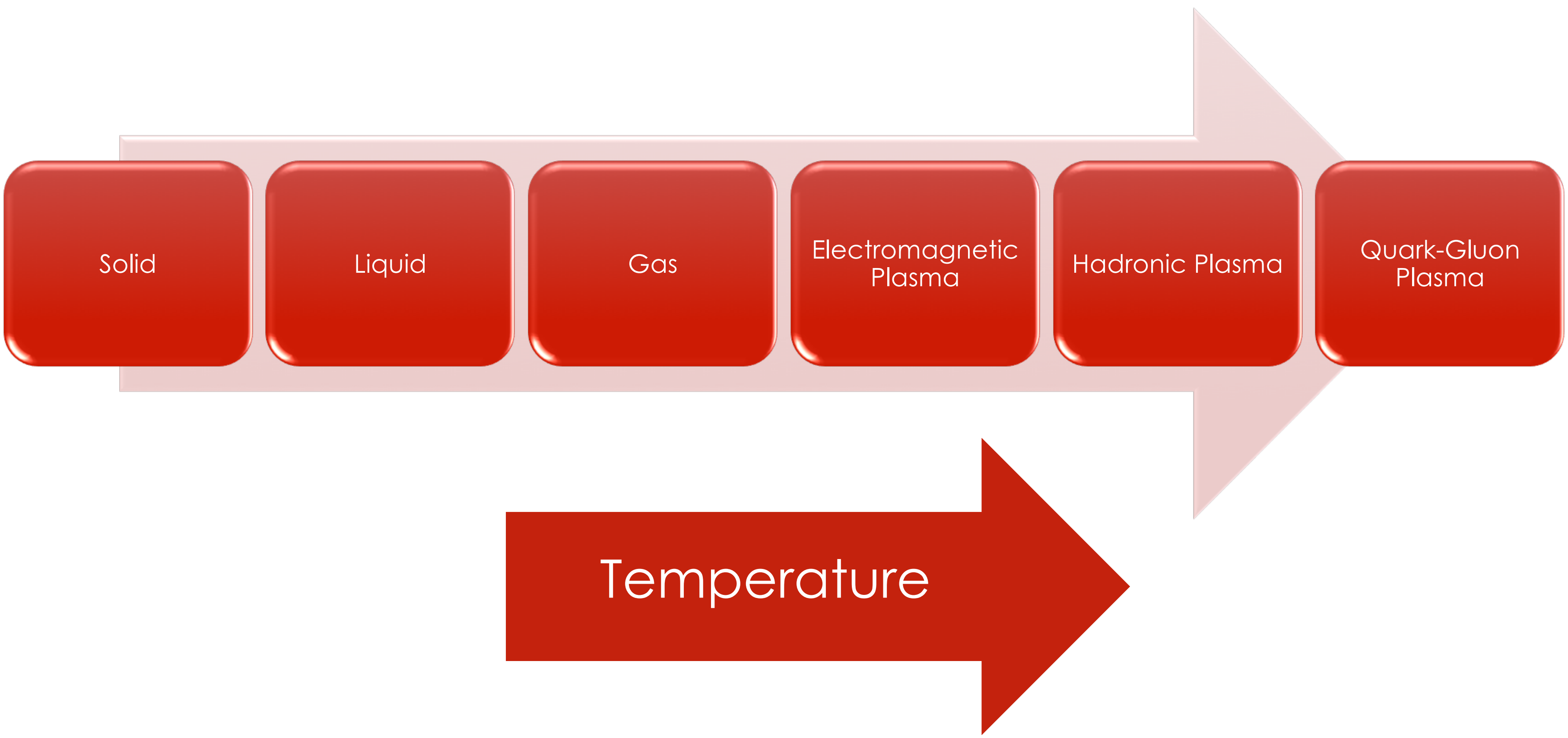
INTRODUCTION TO THE STANDARD MODEL



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



STATES OF MATTER



STATES OF MATTER

- **Gas**
- **Electromagnetic Plasma**
  - When the average thermal energy of a substance is hot enough to separate electrons from their atomic nuclei
- **Hadronic Plasma**
  - When the average thermal energy of a substance is hot enough to dissolve nuclei into protons, neutrons, and other hadrons
- **Quark-Gluon Plasma**
  - When the average thermal energy of a substance is hot enough to break down hadrons into deconfined quarks and gluons

THE NEUTRAL ρ-MESON AND ITS PROPERTIES

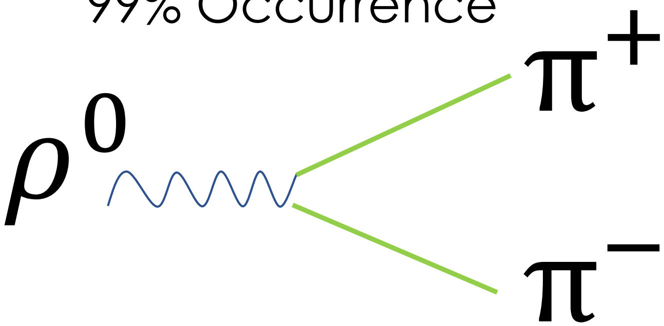
$d\bar{d}$

$u\bar{u}$

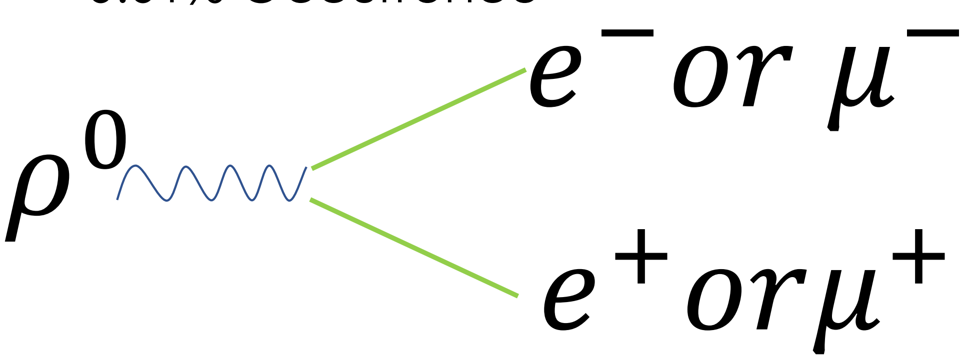
- A meson is a particle composed of two quarks (a quark and an antiquark)
- There are 2 ways to construct a neutral ρ-meson
- This particle has possibilities for decay: a pair of dileptons or a pair of pions

THE DECAY OF THE ρ-MESON

99% Occurrence



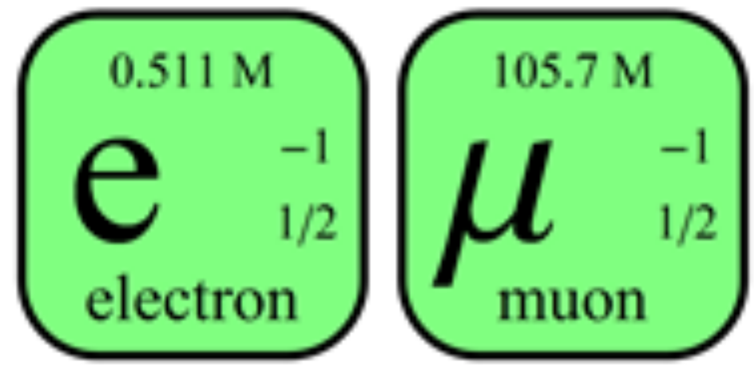
0.01% Occurrence



- Due to the strong nuclear force interaction, pion pion decay is the more probable outcome as opposed to the dilepton decay

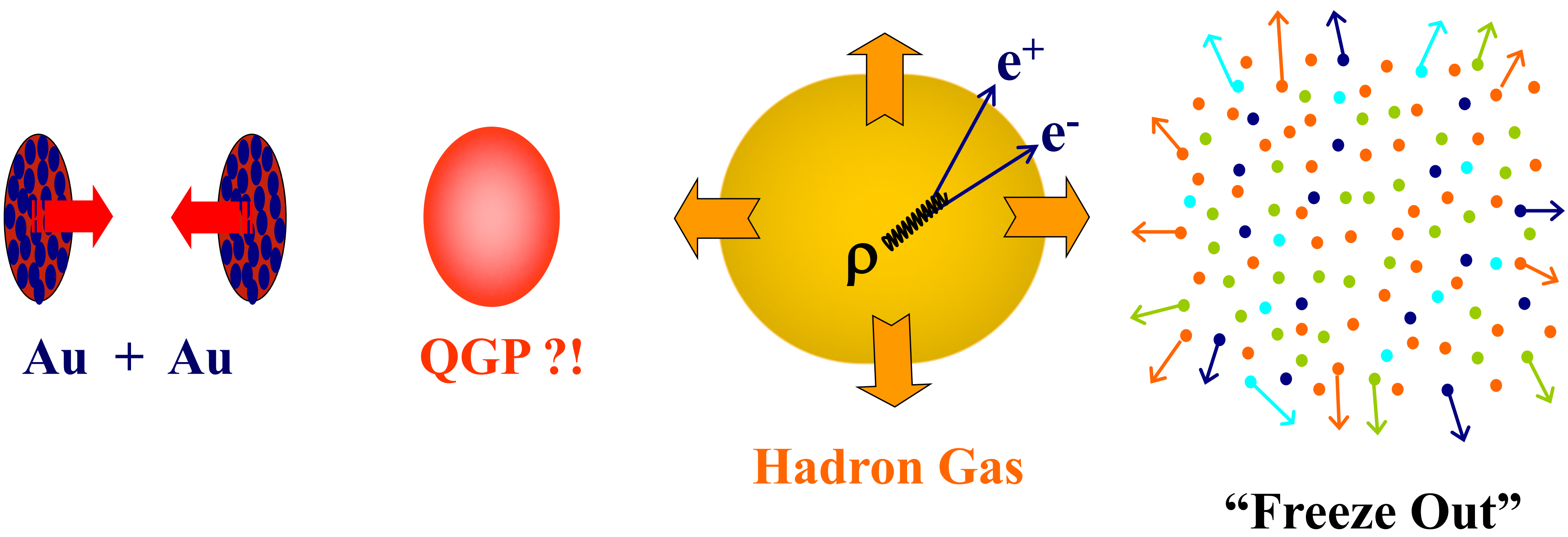
UTILITY OF DILEPTON PAIRS

- Can be analyzed during heavy ion collisions
- Can probe the spectral properties of hot, dense media, particular 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 ρ DECAYS



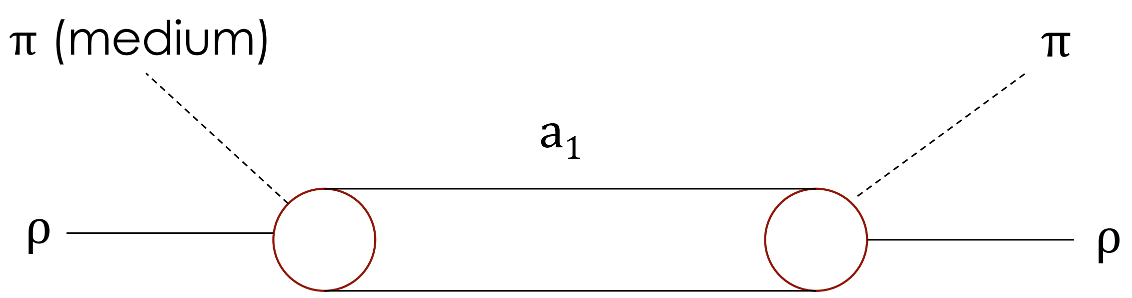
DILEPTON PAIR PRODUCTION RATE

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

- 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 ρ-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 ρ-meson in the vacuum due to the two pion decay
- a characterizes the mass modification
- $\Gamma_{\rho}=\frac{{g_{\rho}}^{2}}{6\pi} * \frac{M}{8} * \left(\frac{M}{0.8}\right)^{4} * \left(1+\frac{2*c_{\pi}}{e^{\frac{q_0}{2T}}-1}\right)$ is the vacuum width for the decay into two pions
- g_{ρ} is the coupling constant

RHO MESON INTERACTIONS WITH MESONIC MATTER

$$\Sigma_{\rho M}(M,q,T) = -im_\rho\left(\frac{T}{0.15}\right)^{\alpha_I}(\Gamma_1+\Gamma_2)+Re(\Sigma_{\rho M})$$

- $\Gamma_1 = \Gamma_0 * \left(\frac{M+0.1}{1.3}\right)^5 \left(\frac{\Lambda_1^2+m_\rho^2}{\Lambda_1^2+M^2}\right)^8$
- $\Gamma_2 = \left[b(M) * \left(\frac{q}{0.4}\right)^3 + (1-b(M))\left(\frac{q}{0.15}\right)^2\right]\left(\frac{\Lambda_2^2+m_\rho^2}{\Lambda_2^2+q^2}\right)^2 * \frac{0.001}{1+25*M^6}$
- $b(M) = \frac{1}{e^{\left(\frac{M-0.2}{0.1}\right)}+1}$
- $\mathrm{Re}(\Sigma_{\rho M}) = \left\{M < 0.75,\ (-0.01)c_m m_\rho\left(\frac{T}{0.15}\right)^{\alpha_R};\ 0.75 < M < 1.2,\ c_m m_\rho\left(\frac{T}{0.15}\right)^{\alpha_R}\left(\frac{M-0.85}{10}\right);\ 1.2 < M,\ (0.035)c_m m_\rho\left(\frac{T}{0.15}\right)^{\alpha_R}\right\}$

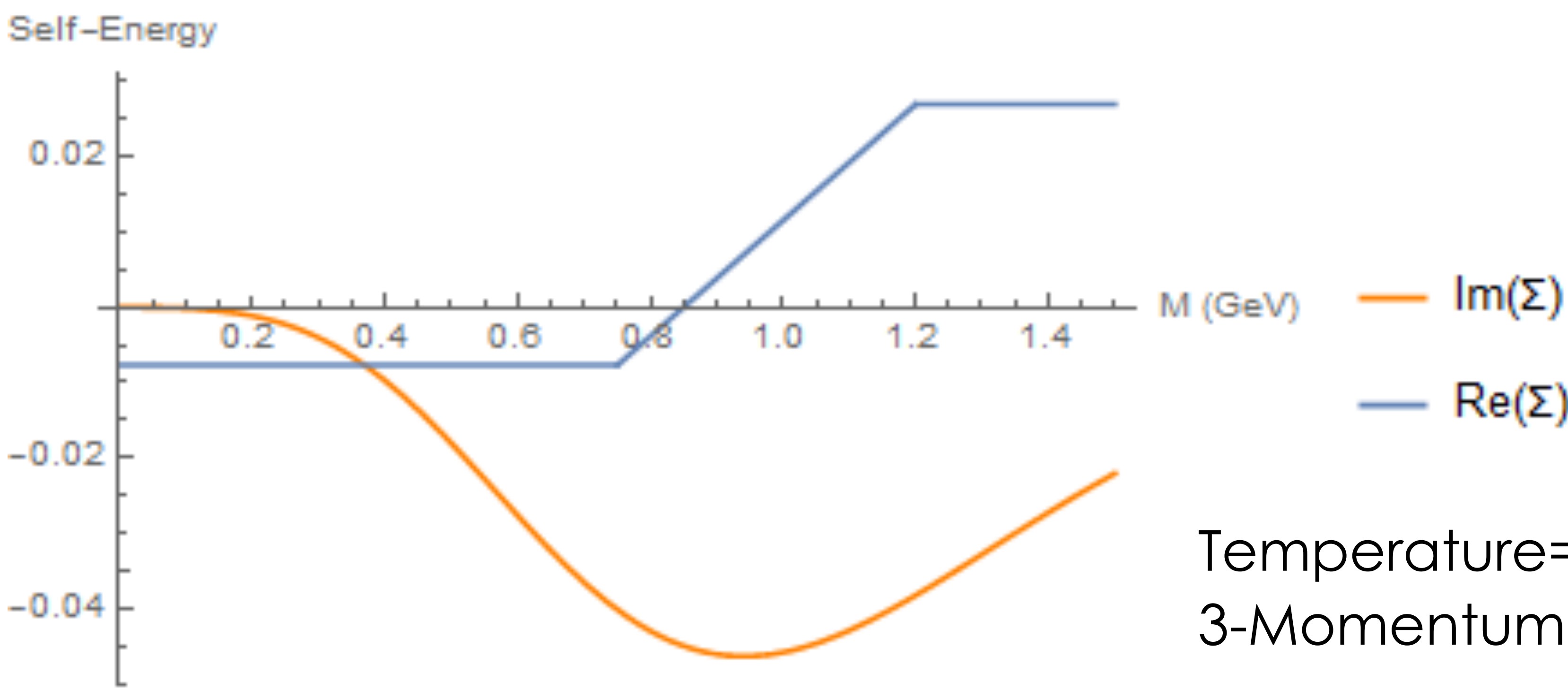
- This term describes how the ρ-meson interacts with other mesons

DATA COMPARISON

MOMENTUM DEPENDENT PARAMETERIZATION

- $c_m = 2.0166 - 2.179 * q$ -Real Vacuum Coefficient
- $\alpha_R = \{q < 0.5, 5.02569\left(1 - \frac{q}{0.5}\right); q \geq 0.5, 0\}$ -Real Temperature Exponent
- $\alpha_I = \{q \geq 0.5,\ 3.93722;\ q < 0.5,\ 10.3502 - \frac{10.3502 - 3.9372}{0.5} * q\}$ -Imaginary Temperature Exponent
- $\Lambda_1 = 1.235 + e^{1.3907 - 2.8 * q}$
- $\Lambda_2 = 0.68997 + 78498 * \frac{q^{0.000015} - 18.584 * 0.0538}{(q^{-1.4774} - 24.2505 * 0.0538)^2 + 0.17}$
- $\Gamma_0 = 0.19 + 218309 * \frac{1 - q^{8.121 * 10^{-6}}}{(1 - q^{-3.086})^2 + 0.4533^2} + 0.2005 * q^2$ -Primary Decay Width Coefficient

SELF-ENERGY IN MESONIC MATTER



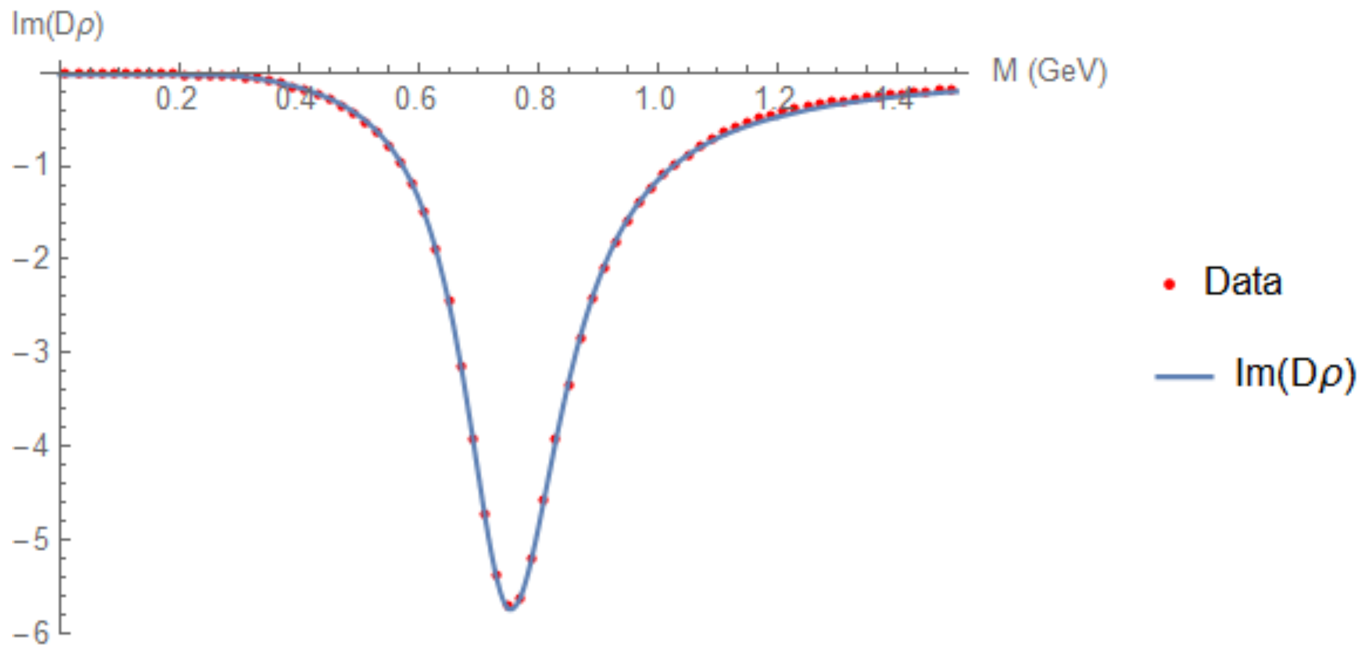
Temperature=0.15 GeV
3-Momentum=0.3 GeV

IN-MEDIUM PROPAGATION

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

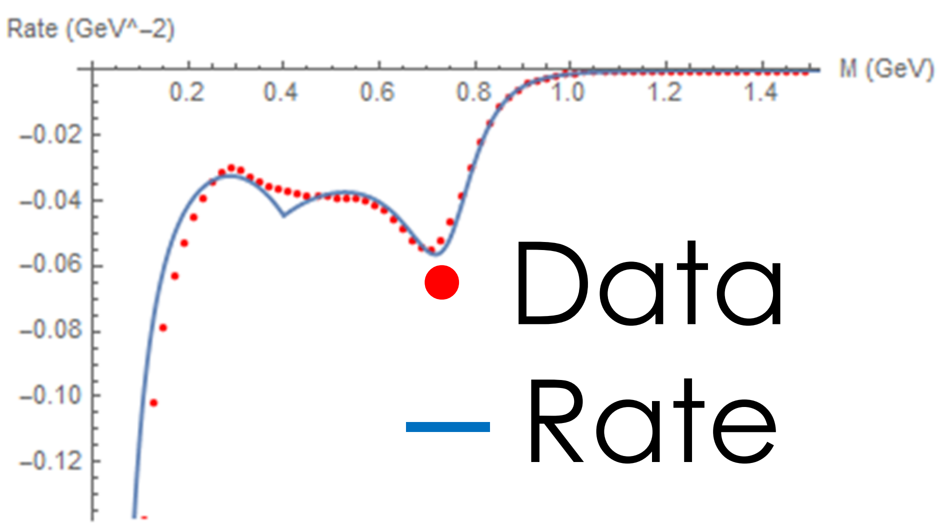
Temperature=0.15 GeV

3-Momentum=0.3 GeV

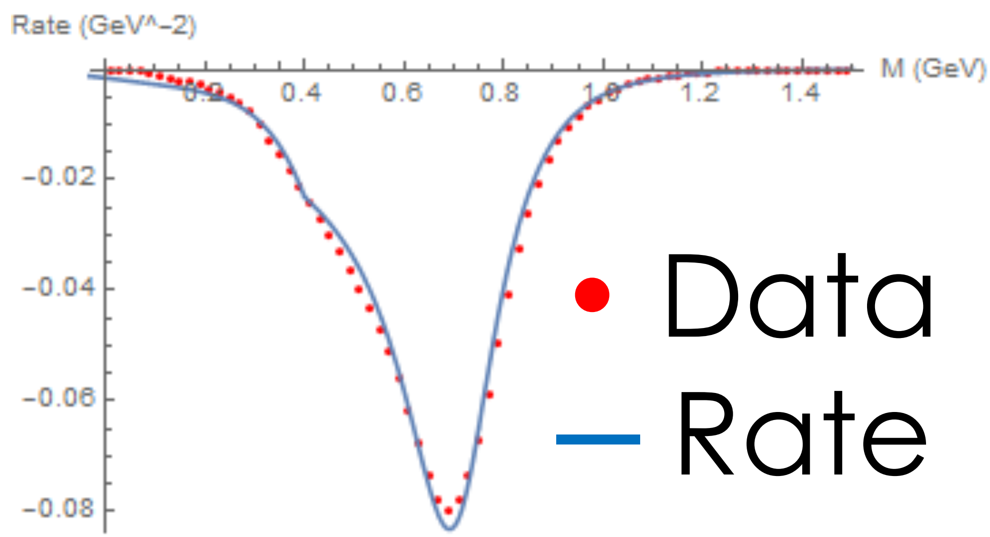


COMPARISON OF THE PARAMETERIZATION WITH THE CALCULATED DILEPTON RATE

Temperature=0.15 GeV,
3-Momentum=0.3 GeV



Temperature=0.18 GeV,
3-Momentum=0.1 GeV



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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