DI-MUON PRODUCTION IN HEAVY ION COLLISIONS AT LHC: A SIGNAL FOR QUARK-GLUON DECONFINEMENT.

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INTRODUCTION

The process of di-muon production in heavy ion collisions at very high energies is a clean probe of the quark-gluon deconfinement phase transition. Low-mass dileptons are one of the electromagnetic probes which reveal the entire thermal evolution of a heavy ion collision. Their invariant mass spectrum is a direct measurement of the in-medium hadronic spectral function in the vector channel. For invariant masses below $1\ GeV$ the spectrum is dominated by the ρ meson. Its short lifetime and large coupling to pions and muons makes it an ideal test particle to sample in-medium changes of its parameters such as mass, width and leptonic decay constant.

FINITE ENERGY QCD SUM RULES

The starting point is the light-quark vector current correlator, which at $T = 0$ can be written as

$$\begin{aligned}\Pi_{\mu\nu}(q^2) &= i\int d^4x e^{iq\cdot x}\langle 0|T\left[\mathcal{V}_\mu(x)\mathcal{V}_\nu^\dagger(0)\right]|0\rangle \\ &= (-g_{\mu\nu}+q_\mu q_\nu)\,\Pi_1(q^2),\end{aligned}$$

where $\mathcal{V}_\mu(x) = (1/2)[:\bar{u}(x)\gamma_\mu u(x) - \bar{d}(x)\gamma_\mu d(x):]$ is the conserved vector current and q_μ is the four-momentum transfer.

Finite Energy Sum Rules (FESR) rely on two pillars, the Operator Product Expansion (OPE) of current correlators at short distances beyond perturbation theory

$$\Pi^{\text{QCD}}(q^2) = C_0\hat{I} + \sum_{N=0} C_{2N+2}(q^2)\langle 0|\hat{O}_{2N+2}|0\rangle,$$

and Cauchy's theorem in the complex squared energy s-plane.The theorem allows to relate QCD information on the circle of certain radius s_0 to hadronic physics on the real positive s-axis.
This leads to the FESR

$$\begin{aligned}&(-1)^{N-1}C_{2N}\langle O_{2N}\rangle = \\ &8\pi^2\Big[\int_0^{s_0} ds\ s^{N-1}\frac{1}{\pi}\text{Im}\Pi^{\text{HAD}}(s) \\ &- \frac{1}{2\pi i}\oint_{C(|s_0|)} ds\ s^{N-1}\Pi^{\text{QCD}}(s)\Big],\end{aligned}$$

$\text{Im}\Pi^{\text{HAD}}(s)$ is related with the hadronic spectral function and the latter is well approximated by the Breit-Wigner form

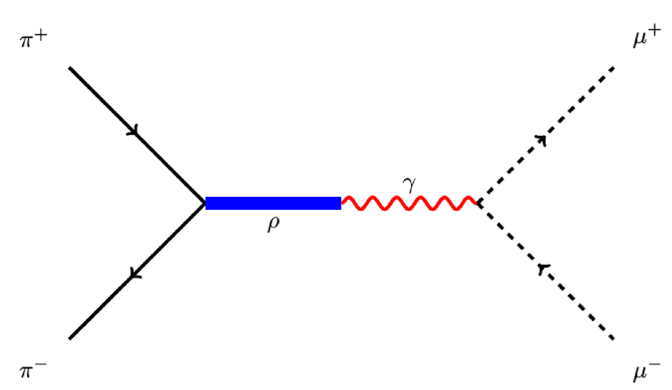
$$\frac{1}{\pi}\text{Im}\Pi^{\text{HAD}}(s) = \frac{1}{\pi}\frac{1}{f_\rho^2}\frac{M_\rho^3\Gamma_\rho}{(s-M_\rho^2)^2+M_\rho^2\Gamma_\rho}.$$

ANALYSIS.

At finite temperature all hadronic parameters become T dependent. The solution from FESR for all hadronic parameters as a function of T are the following

$$\begin{aligned}\Gamma_\rho(T) &= \Gamma_\rho(0)[1-(T/T_c)^3]^{-1}, \\ M_\rho(T) &= M_\rho(0)[1-(T/T_M^*)^{10}], \\ f_\rho(T) &= f_\rho(0)[1-0.3901(T/T_c)^{10.75} \\ &+ 0.04155(T/T_c)^{1.27}].\end{aligned}$$

With these solutions we proceed to compute the dimuon thermal rate in the hadronic phase originating from ρ decays.



We consider processes where pions annihilate into ρ's which in turn decay into dimuons, and use of vector meson dominance.

$$\begin{aligned}\frac{dN}{d^4x d^4K} &= \frac{\alpha^2}{48\pi^4}\left(1+\frac{2m^2}{M^2}\right)\left(1-\frac{4m_\pi^2}{M^2}\right) \\ &\times\sqrt{1-\frac{4m^2}{M^2}}\,e^{-K_0/T}\mathcal{R}(K,T)\text{Im}\Pi_0^{\text{res}}(M^2),\end{aligned}$$

where N is the number of muon pairs per unit of infinitesimal space-time and energy-momentum volume, with x^μ the space-time coordinate and K^μ the four-momentum of the muon pairs, α is the electromagnetic coupling, m is the muon mass, m_π is the pion mass and M is the dimuon invariant mass.

RESULTS

To relate the temperature change to the time evolution of the system, we neglect a possible small transverse expansion [assume that it is entirely longitudinal] and use the cooling law

$$T = T_0\left(\frac{\tau_0}{\tau}\right)^{v_s^2},$$

where $v_s^2 = 1/3$ is the square of the sound velocity for an ideal gas.

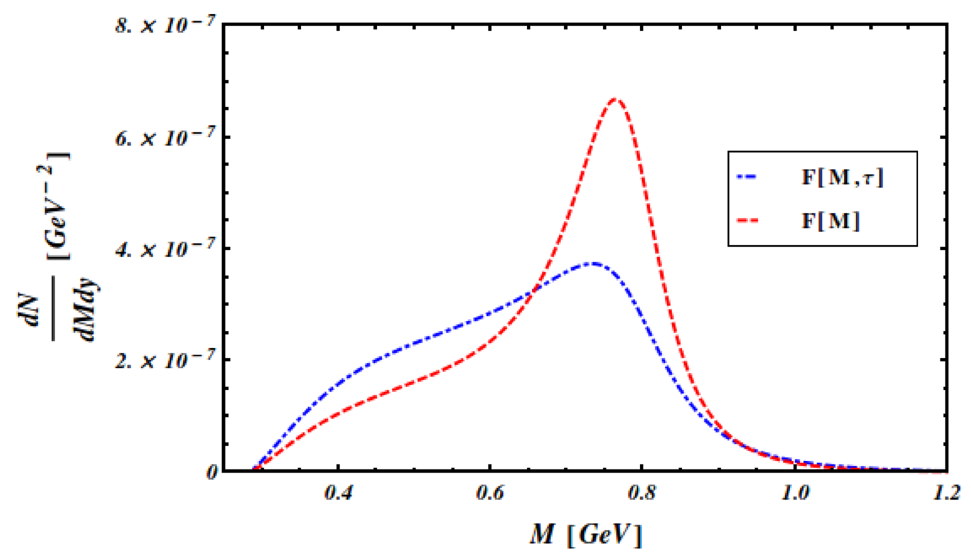


Figure 1: Invariant dimuon mass distribution around ρ peak, with and without thermal evolution.

We show the result for dN/dM compared to the NA60 data around the ρ peak [for $T_0 = T_c = 0.197\ GeV$, $T_f = 0.1\ GeV$]. The theoretical result provide an excellent description of the data around the ρ peak.

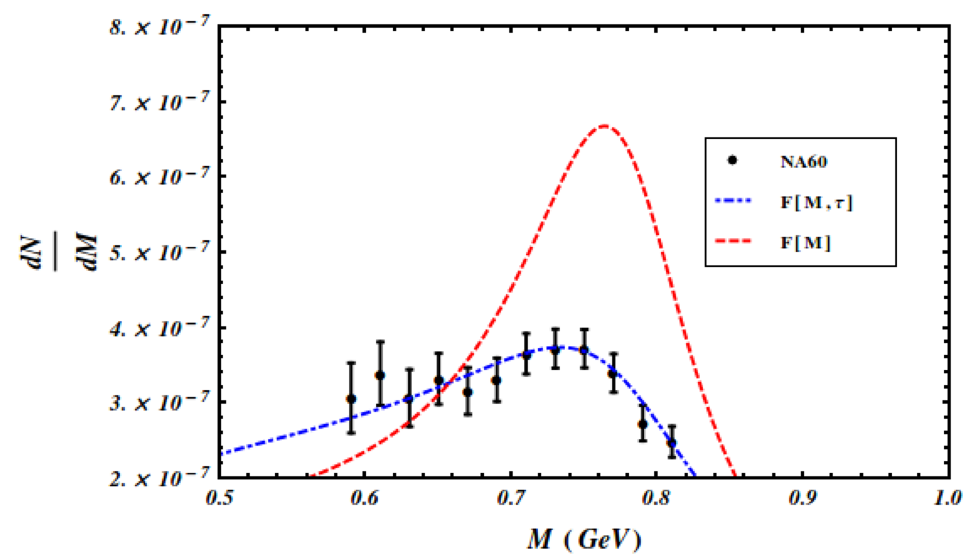


Figure 2: Invariant dimoun mass distribution (with and without thermal evolution) compared to NA60 data.

CONCLUSION

This approach involves as sole inputs the temperature dependence of the rho-meson mass, width and leptonic coupling. This temperature dependence is obtained from FESR, so that the di-muon production rate is essentialy a parameter-free prediction.
We have shown that the FESR, being a description entirely in the framework of QCD at finite temperature, provides support to many-body descriptions of in-medium hadron properties.

FUTURE RESEARCH

1. Including the effects of transverse expansion.
2. Exploring other cooling laws.
3. Analyse the effect of other approximations for the hadronic spectral function.
4. Verify the agreement with data from other experiments and other kind of nuclei.

REFERENCES

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