NA60 and BR Scaling in Terms of the Vector Manifestation: A Model Approach

G.E. Brown\textsuperscript{1} and Mannque Rho\textsuperscript{2}

\textsuperscript{1} Department of Physics and Astronomy
State University of New York, Stony Brook, NY 11794-3800
\textsuperscript{2} Service de Physique Théorique, CEA Saclay, 91191 Gif-sur-Yvette cédex, France

It is pointed out that the comparison between the recent NA60 dimuon data and the so-called “Brown-Rho (BR) scaling” as presented at QM2005 is not founded on a correct interpretation of the prediction of BR scaling as formulated in 1991 and modernized recently and hence the conclusion drawn by both the experimental and theoretical speakers that “BR scaling is ruled out by NA60” is erroneous and should be disregarded. We use a simplified model description of how the vector manifestation of hidden local symmetry theory enters into the dilepton production, relegating more rigorous discussions to a follow-up paper.

At Quark Matter 2005, five talks \textsuperscript{1, 2, 3, 4, 5} flashed Fig.1 to declare Brown-Rho (BR) scaling “ruled out” by experiment based on the “apparent lack” of that theory as interpreted by Rapp \textsuperscript{6} to explain the NA60 dimuon data. We request that the readers remove the initials “BR” from the calculated (green) curve with our names erroneously associated with it, in that it has nothing to do with what we believe BR scaling \textsuperscript{7} to be, which is clearly re-outlined recently in \textsuperscript{8}. We try in this note using the simplest possible models and languages, to explain why the green curve should be removed from the figure, or at least why our names are not to be associated with it. There are three main points in our arguments:

1. the “parametric mass” to which BR scaling – hence chiral symmetry aspect – is directly connected and the physical (or pole) mass of the vector meson should be distinguished;

2. BR scaling which has to do with the “intrinsic property” of the vacuum and Rapp-Wambach (RW) mechanism \textsuperscript{9} which has to do with many-body effect (“sobar” excitations) should be “fused,” because both are present;

3. Vector dominance (VD), which was employed in calculating the green curve, is badly violated over most of the range of temperatures and densities involved and it is obvious that VD gave most of the shape and height of the green curve. Schematizing the Harada-Yamawaki renormalization group approach \textsuperscript{10} down to bare minimum, we shall show how this comes about.

We give a more precise and comprehensive discussion in the accompanying paper \textsuperscript{11} where all three points given above are treated in light of the modern development of hidden local symmetry theories that represent low-energy QCD, with a focus on Harada-Yamawaki hidden local symmetry and its vector manifestation (VM) \textsuperscript{12} which is the key point of the theoretical framework of BR scaling. In this paper, we will focus on the points (2) and (3) with only a brief reference in a footnote (see \textsuperscript{13}) to the point (1) which requires a precise theoretical definition.

Point (2) is easily dealt with because Rapp calculated the fusion of BR and RW in Fig.5 of \textsuperscript{8}. As will be noted below, he incorrectly used vector dominance (VD) in doing so, but he did show that the “fusing” changed both BR and RW curves substantially. This is because if the \(\rho\)-meson mass drops \textsuperscript{14}, as in BR, the VD coupling \(m_{\rho}^2/g\) should be replaced by \(m_{\rho}^2/g^*\) (where \(g\) stands for the gauge coupling constant) in the amplitude for dilepton production. As explained in \textsuperscript{11}, both the physical \(\rho\)-meson mass and the gauge coupling are expected to start dropping when temperature reaches \(\sim 125\) MeV, so the dilepton production will have the correction factor \((m_{\rho}^*/m_{\rho})^2\) from \(\sim 125\) MeV to the critical temperature \(\sim 175\) MeV. Also in this regime, with dropping \(\rho\) mass, more decays of the sobar \(N^*(1520)\) will go by way of the \(\rho\)-meson and fewer into dileptons.

Point (3) that vector dominance is inapplicable in generic hadronic system (with the pionic EM form factor in free space being an exception) was first established by Harada and Yamawaki in 2001 \textsuperscript{15} and is extensively reviewed in \textsuperscript{8}. A parameter \(a\) in hidden local theory of Harada and Yamawaki which figures importantly in the EM current (see \textsuperscript{11}) is equal to 2 for vector dominance, but moves in medium quickly towards 1, its value at the fixed point – called vector manifestation fixed point \textsuperscript{12} – that is reached when chiral symmetry is restored where

\[\text{FIG. 1: NA60 results compared with the Rapp-Wambach description (in blue) and so-called “BR scaling” (in green).}\]
both $m^*_\rho$ and $g^*$ also have their fixed point values of zero. The renormalization group flow of $a$ as function of temperature and/or density is not well known except at near zero temperature and density and in the vicinity of the vector manifestation fixed point. Furthermore in heavy-ion processes, temperature and density must be correlated. Here we will ignore this correlation. We believe the conclusion we will arrive at is sound.

Let us take the temperature dependence in the form of the most naive scaling,

$$a(T) = \frac{2}{1 + T/T_c}$$

(1)

which interpolates between $a = 2$ at $T = 0$ and $a = 1$ at $T = T_c$. Since the dilepton production is quadratic in $a$, the ratio of the one with $a$ moving towards its fixed point 1 compared with the vector dominance one is

$$\int_0^{T_c} \left( \frac{1}{1 + T/T_c} \right)^2 \frac{dT}{T_c} \left[ \int_0^{T_c} \frac{dT}{T_c} \right]^{-1} = 1/2.$$  \(2\)

This means that in our simplest model, the cross section is cut down by a factor of $2$.

We expect the factor of $2$ to be the lower limit for two related reasons: (1) temperature dependence of the vector meson mass; (2) $a \rightarrow 1$ in baryonic systems.

We have argued in a number of papers [16, 17, 18, 19] that the “melting” of the soft glue is responsible for hadronic masses to decrease with temperature. In Fig. 1 of Brown, Lee and Rho [18], it is shown from unquenched lattice calculations that the melting of the soft glue begins at $T = 125$ MeV; none is melted before this. In contrast, the temperature dependence in the formula used by Rapp [6]

$$\frac{m^*_\rho}{m_\rho} = (1 - 0.15 n/n_0)(1 - (T/T_c)^2)^{0.3}$$

(3)

begins lowering the $\rho$-meson mass from $T \sim 0$ and by $T = 125$ MeV

$$[1 - (T/T_c)^2]^{0.3} = 0.81$$

(4)

with $T_c = 175$ MeV; i.e., the mass in his calculation decreased 19% at the point at which it begins decreasing in the lattice calculations. This is contrary to what one expects from the hidden local symmetry theory with vector manifestation [13, 20].

In our model, we should spread the 50 MeV (=175 MeV-125 MeV) in temperature over the interval $M = 0.2 - 0.8$ GeV, but since medium effects begin only at 125 MeV we should take that as the lower limits in the integrand in Eq. (2), which now gives $\sim 0.3$ rather than $1/2$. We will actually argue below that in dense medium, the factor will be $1/4$.

As mentioned, the vector dominance coupling has the factor $m^*_\rho/g^*$ in it and the square enters in the cross section, so this limits further the contribution from high temperature region in that Rapp’s $m^*_\rho$, as that of BR scaling, goes to zero as $T \rightarrow T_c$.

Rapp (private communication) estimates that with his parametrization “the effect of baryon density and temperature in the dropping mass are comparable” whereas putting together our above effects we find the temperature dependent effects to be an order of magnitude smaller than Rapp does. We should therefore remove almost all of Rapp’s contributions to the green curve from temperature and concentrate on the density dependent effects.

We know from Trnka et al [22] that the $\omega$-meson in Sn has a density dependence consistent with that of BR scaling. We expect the same density dependence for the $\rho$-meson since the $\omega$ and $\rho$ are in the same multiplet of $U(2)$. Indeed Naruki et al [23] find this to be the case in their experiments. The mass drop observed is somewhat smaller than that predicted by BR scaling, $\sim 20\%$. As discussed in [11], this difference can be explained by dense loop corrections that appear at higher order than BR scaling. Now in the presence of density, it is found [8, 22] that the constant $a$ goes precociously to 1 (see the discussion in [8]). In fact, this is already realized at the level of one baryon, namely in the EM form factor of the nucleon where vector dominance is maximally violated with the constant $a$ going to $1$. This suggests that the dilepton production that takes place in dense matter must be cut down by a factor of $4$ compared with that obtained by Rapp.

[1] E. Scomparin, Plenary talk (exp) at QM 2005
[2] S. Damjanovici, Parallel talk (exp) at QM 2005
[3] L. Maiani, Plenary talk (theory) at QM 2005
[4] I. Tseruya, Concluding talk (exp) at QM 2005
[5] C. Gale, Plenary talk (theory) at QM 2005
[6] R. Rapp, unpublished.
[7] G.E. Brown and M. Rho, Phys. Rev. Lett. 66 (1991) 2720.
[8] G.E. Brown and M. Rho, Phys. Rept. 396 (2004) 1.
[9] R. Rapp and J. Wambach, Adv. Nucl. Phys. 25 (2000) 1.
[10] M. Harada and K. Yamawaki, Phys. Rept. 381 (2003) 1.
[11] G.E. Brown and M. Rho, “NA60 and BR scaling in terms of the vector manifestation: Formal considerations,” nucl-th/0509002.
[12] M. Harada and K. Yamawaki, Phys. Rev. Lett. 86 (2001) 757.
[13] In a systematic calculation with hidden local symme-
try theory with the vector manifestation, Harada and Sasaki \cite{20} showed that in addition to the parametric mass of the $\rho$-meson $\sqrt{agf_\pi}$ which is connected to the soft glue, there is an important thermal loop correction that assures that the $\rho$ mass actually increases $\propto T^4$ rather than decreases, satisfying the DEI theorem \cite{21}. This means that in some range of temperature, the vector meson mass could be increasing rather than decreasing as naive consideration indicates.

\cite{14} Here we are being cavalier about the distinction mentioned in \cite{13} between the parametric mass that goes like $\sqrt{agf_\pi}$ and the physical (pole) mass that has a thermal loop correction. See \cite{11} for a precise definition. It is the parametric mass that enters in BR scaling.

\cite{15} M. Harada and K. Yamawaki, Phys. Rev. Lett. 87 (2001) 52001.

\cite{16} G.E. Brown, L. Grandchamp, C.-H. Lee and M. Rho, Phys. Rept. 391 (2004) 353

\cite{17} G.E. Brown, C.-H. Lee and M. Rho, Nucl. Phys. A747 (2005) 530.

\cite{18} G.E. Brown, C.-H. Lee and M. Rho, “The Ideal liquid discovered by RHIC: Infrared slavery above and hadronic freedom below $T_c$,” nucl-th/0507011

\cite{19} G.E. Brown, C.-H. Lee and M. Rho, “The STAR $\rho^0/\pi^-$ Ratio in Au-Au Peripheral Collisions at RHIC and the Vector Manifestation of Hidden Local Symmetry,” nucl-th/0507073

\cite{20} M. Harada and C. Sasaki, Phys. Lett. B537 (2002) 280.

\cite{21} M. Dey, V.L. Eletsky and B.L. Ioffe, Phys. Lett. B252 (1990) 620.

\cite{22} D. Trnka et al., Phys.Rev.Lett. 94 (2005) 192303.

\cite{23} M. Naruki et al., “Experimental signature of the medium modification for $\rho$ and $\omega$ mesons in 12 GeV p+A reactions,” nucl-ex/0504016

\cite{24} M. Rho, hep-ph/0502049