The effects of deformation parameter on thermal widthth
of moving quarqonia in plasma

J. Sadeghi $^a$ and S. Tahery $^a$

$^a$ Sciences Faculty, Department of Physics, University of Mazandaran,
P. O. Box 47415-416, Babolsar, Iran

December 31, 2014

Abstract

In general we can say that the thermal width of quarqonia corresponds to imaginary part of potential. The gravity dual of theories give explicit form of potential as $V_{Q\bar{Q}}$. The Variable gravity dual’s backgrounds of moving pair in plasma have different results for potential. Our paper shows that the first order deformation parameter $c$ in warp factor lead us to take new results. We compare our results to case of no deformation parameter is in metric background. We will find out although in a deformed AdS meson is not visible in some regions of bulk, but thermal width is similar to the case that dipole is in $AdS_5$. Also, we note here in a deformed AdS, meson feels moving plasma in all values of velocity.

$^a$Email: j.sadeghi@umz.ac.ir
$^\dagger$Email: s.tahery@stu.umz.ac.ir
1 Introduction

The AdS/CFT correspondence is [1-5] between a string theory in AdS space and conformal field theories in physical space-time. It leads to an analytic semi-classical model for strongly coupled QCD. It has scale invariance, dimensional counting at short distances and color confinement at large distances. This theory describes the phenomenology of hadronic properties and demonstrate their ability to incorporate such essential properties of QCD as confinement and chiral symmetry breaking. In the AdS/CFT point of view the $AdS_5$ play important role in describing QCD phenomena. So in order to describe a confining theory, the conformal invariance of $AdS_5$ must be broken somehow. Two strategies AdS/QCD background have been suggested in the literatures hard-wall [6-12] and soft-wall model [13-31]. In hard-wall model to impose confinement and discrete normalizable modes that is to truncate the regime where string modes can propagate by introducing an IR cutoff in the fifth dimension at a finite value $z_0 \sim \frac{1}{\Lambda_{QCD}}$. Thus, the hard-wall at $z_0$ breaks conformal invariance and allows the introduction of the QCD scale and a spectrum of particle states, they have phenomenological problems, since the obtained spectra does not have Regge behavior. To remedy this it is necessary to introduce a soft cut off, using a dilaton field or using a warp factor in the metric [6, 18]. These models are called soft wall models. The soft-wall and hard-wall approach has been successfully applied to the description of the mass spectrum of mesons and baryons, the pion leptonic constant, the electromagnetic form factors of pion and nucleons, etc. On the other hand the study of the moving heavy quarqonia in space-time with AdS/QCD approach plays important role in interaction energy [32-35]. By using different metric background we see different effect on interaction energy.

Evaluation of $\text{Im} V_{QQ}$ will yield to determine the suppression of $QQ$ in heavy ion collision[36]. The main idea is using boosted frame to have $\text{Re} V_{QQ}$ and $\text{Im} V_{QQ}$ [37] for $QQ$ in a plasma. From viewpoint of holography, the AdS/CFT correspondence can describe a “broken conformal symmetry”, when one adds a proper deformed warp factor in front of the $AdS_5$ metric structure[38-58]. So, $e^{-cz^2}$ is a negative quadratic correction with $z$, the fifth dimension.

One natural question is about the connection between the warp factor and the potential
In this work, the procedure [36] is followed to evaluate the imaginary part of potential for two cases. First, an $AdS_5$ metric with no deformation parameter in warp factor, and the other is a metric with a “nonzero” $c$. It is interesting to see “what will happen if meson be in a deformed space?”

As expected in the limit $c \to 0$, two warp factors are similar, and “$n$”th order of deformation parameter with “$n$”th power of $c$ is presented in calculations. It is a trend to see effects of deformation parameter on $\text{Re}V_{Q\bar{Q}}$ and $\text{Im}V_{Q\bar{Q}}$ that are evidences for “usual” or “unusual” behavior of meson in compare with the case $c = 0$. It should be mentioned that all of our calculations are for the case that $Q\bar{Q}$ is moving perpendicularly to the joining axis of the pair.

All above informations give us motivation to work on the deformation parameter in $AdS$ metric background on real and imaginary part of potential. For this reason we organized the paper as follows. In section 2, we start with $AdS$ black-hole spacetime with translationally invariant horizon, we assume this metric background for $Q\bar{Q}$ and find some relations for real and imaginary parts of potential with respect to velocity of meson. This simple and routin example will be presented with some analytical results. For a “deformed” space, we consider another metric in section 3 and follow the procedure as before. Because of the complexity of this problem, it is important to choose “what order of $c$, we want to calculate” if one wants analytical results. Section 4 would be our conclusion and see some suggestions for future work.

2 $Q\bar{Q}$ in an AdS black-hole space time

In this section we consider soft-wall metric background in infinite temperature case. So, we present the general relation for real and imaginary parts of potential when the dipole is moving perpendicularly with respect to the wind with velocity $\eta$ [36].

In our case we apply the general result for $AdS$ black hole space time with translationally
invariant horizon, the dual gravity metric will be as:

\[ ds^2 = e^{2A(z)} \left[ -f(z) dt^2 + \sum_{i=1}^{3} dx_i^2 + \frac{1}{f(z)} dz^2 \right], \tag{1} \]

where \( A(z) = -\ln \frac{z}{R} \) and \( f(z) = 1 - (\frac{z}{z_h})^4 \). \( R \) is the AdS curvature radius, also \( 0 \leq z \leq z_h \), \( z_h = \frac{1}{\pi T} \) and \( T \) is boundary field theory’s temperature.

We take advantage from the metric background (1), one can obtain,

\[ G_{00} = \frac{R^2}{z^2} [1 - (\frac{z}{z_h})^4] \tag{2} \]

\[ G_{xx} = \frac{R^2}{z^2} \tag{3} \]

\[ G_{zz} = \frac{R^2}{z^2} [1 - (\frac{z}{z_h})^4]^{-1} \tag{4} \]

we use the following change of variable,

\[ M(z) \equiv G_{00} G_{zz} \tag{5} \]

\[ V(z) \equiv G_{00} G_{xx} \tag{6} \]

\[ P(z) \equiv G_{xx}^2 \tag{7} \]

\[ N(z) \equiv G_{xx} G_{zz} \tag{8} \]

we will arrive at,

\[ \tilde{M}(z) \equiv M(z) \cosh^2 \eta - N(z) \sinh^2 \eta \]

\[ = (R\pi T)^4 \left( \frac{y}{y_h} \right)^4 \left[ \frac{y^4 - y_h^4 \cosh^2 \eta}{y^4 - y_h^4} \right], \tag{9} \]

and

\[ \tilde{V}(z) \equiv V(z) \cosh^2 \eta - P(z) \sinh^2 \eta \]

\[ = \left( \frac{R\pi T}{y_h} \right)^4 [y^4 - y_h^4 \cosh^2 \eta], \tag{10} \]

where \( y = \frac{z}{z} \) and \( y_h = \frac{z}{z_h} \)

(\( * \) is the deepest position of the string in the bulk).

From the following hamiltonian,

\[ H(z) \equiv \sqrt{\frac{\tilde{V}(z) \tilde{V}(z) - \tilde{V}_*}{\tilde{V}_*/M(z)}}, \tag{11} \]
where $\tilde{V}_s$ means $\tilde{V}(z_*)$

one can obtains,

$$H(z) \equiv \sqrt{\frac{(y^4 - 1)(y^4 - y_h^4)}{y^4(1 - y_h^4 \cosh^2 \eta)}}$$ (12)

So the equation of motion and the boundary conditions of the string relates $L$(length of the
line joining both quarks) with $z_*$ as follows,

$$\frac{L}{2} = \int_{r_h}^{\Lambda} \frac{dr}{H(r)}.$$ (13)

So, for the corresponding case we have,

$$\frac{L}{2} = -\int_{0}^{z_*} \frac{dz}{H(z)}.$$ (14)

In order to relation between $S_{str}$ and $z_*$ we find the regularized integral [37],

$$S_{str}^{reg} = \frac{T}{\pi \alpha'} \int_{r_h}^{\Lambda} dr \left[ \sqrt{\frac{M(r)}{\tilde{V}(r)}} \right] \left( \frac{\tilde{V}(r)}{\tilde{V}(r_*)} - 1 \right)^{-1/2} - \sqrt{M_0(r)}]$$

We obtain the following results,

$$LT = \frac{2}{\pi} y_h \sqrt{1 - y_h^4 \cosh^2 \eta} \int_{1}^{\infty} \frac{dy}{\sqrt{(y^4 - 1)(y^4 - y_h^4)}}$$ (16)

and

$$S_{str}^{reg} = T^2 \frac{\sqrt{\lambda}}{y_h} \left[ \int_{1}^{\infty} (dy\frac{y^4 - y_h^4 \cosh^2 \eta}{\sqrt{(y^4 - 1)(y^4 - y_h^4)}} - 1) - \frac{1}{y_h} \right].$$ (17)

where $\lambda = \frac{\alpha'}{\pi}$ is coupling constant of QCD. Finally, we find the real part of potential as

$$ReV_{QQ} = \frac{S_{str}^{reg}}{T}.$$ (18)

From hypergeometric functions[59], these integrals give us following relations,

$$LT = \frac{2\sqrt{2\pi}}{\Gamma(\frac{1}{4})^2} y_h \sqrt{1 - y_h^4 \cosh^2 \eta} 2F_1(\frac{1}{2}, \frac{3}{4}, \frac{5}{4}, y_h^4),$$ (18)

and

$$ReV_{QQ} = \frac{\sqrt{\lambda} \sqrt{2\pi^3}}{y_h} \frac{\Gamma(\frac{1}{4})^2}{\Gamma(\frac{1}{4})^2} [2F_1(\frac{1}{2}, \frac{3}{4}, \frac{5}{4}, y_h^4)].$$ (19)
Figure 1: LT as a function of $y_h$ for different values of $\eta$. Dipole is oriented perpendicularly to the hot wind and $c = 0$.

At the next step, we are ready to arrange the imaginary part of potential which is important in the suppression of $Q\bar{Q}$ in heavy ion collision. For $\tilde{M}(z_*) > 0$ the imaginary part of the $V_{Q\bar{Q}}$ would be [37]:

$$\text{Im} V_{Q\bar{Q}} = -\frac{1}{2\sqrt{2}\alpha'} \sqrt{M_*} \left[ \frac{V_*'}{2V_*''} - \frac{V_*'}{V_*'} \right].$$

(20)

After some algebraic calculation, the equation (20) will be as,

$$\frac{\text{Im} V_{Q\bar{Q}}}{T} = -\frac{\pi \sqrt{\lambda}}{24\sqrt{2}y_h} \sqrt{1 - y_h^4 \cosh^2 \eta} \left(3y_h^4 \cosh^2 \eta - 1\right).$$

(21)

It is satisfied by condition $\text{Im} V_{Q\bar{Q}} < 0$. Imaginary part of potential should be negative because it appears in an exponential function and should exhibit a decaying behavior. For $\tilde{M}(z_*) < 0$ we have $\text{Im} V_{Q\bar{Q}} \approx 0$, as we expected [37]. The behavior of quarqonia is shown in some figures. Figure 1 is showing LT as a function of $\eta$ for different values of $y_h$. It illustrates the function arises from zero to maximum value of LT with growing $y_h$ from 0 to 1 and $y_h(\text{LT})_{\text{max}} \approx 0.85$. 
Figure 2: Scaled real part of potential as a function of $\eta$ when $Q\bar{Q}$ is oriented perpendicularly to the hot wind and $c = 0$.

Figure 3: Scaled imaginary part of potential as a function of $\eta$ when $Q\bar{Q}$ is oriented perpendicularly to the hot wind and $c = 0$. 
For figure 2, $\text{Re} \, V_{Q\bar{Q}}$ when LT has maximum value is chosen to survey its behavior. The reader can assume any arbitrary $\text{Re} \, V_{Q\bar{Q}}$ with different values of LT. In our schema $\text{Re} \, V_{Q\bar{Q}}$\text{LT}_\text{max}$ is scaled with $T\sqrt{\lambda}$. It shows that for small values of $\eta$, the $Q\bar{Q}$ pair can not feel moving plasma ($\text{Re} \, V_{Q\bar{Q}}$ is zero for some values of $\eta$), after that it increases with velocity.

In last figure of this section, $\text{Im} \, V_{Q\bar{Q}}$\text{LT}_\text{max}$ is shown as a function of $\eta$ and it is scaled with $T\sqrt{\lambda}$. It indicates the thermal width decreases when $\eta$ is increasing, until it reaches to a minimum value.

3 \ Q\bar{Q} \text{ in an deformed AdS}

In this section, we apply the same calculations as before for the case $A(z) = \ln \frac{z}{R} - \frac{1}{4}cz^2$. In that case $c$ is deformation parameter and also field theory temperature is same as previous section. We refer the reader to [60] for the reasons why in deformed AdS model with quadratic correction in warp factor the “temperature” take the form of for AdS-SW BH background. So, we have a deformed AdS that in the limit $c \to 0$ is $AdS_5$.

Here we have the metric (1) as last section but the warp factor is different as mentioned above. Therefore, our corresponding calculation in case of $L$, $\text{Re} V_{Q\bar{Q}}$ and $\text{Im} V_{Q\bar{Q}}$ give us motivation to compare results between two different metric background. This comparing results help us to understand the effect of deformation parameter on the physical quantity such as interaction energy. So, we choose the following change of variable.

$$M(z) \equiv \frac{R^4}{z^4} e^{-cz^2}$$  \hspace{1cm} (22)

$$V(z) \equiv \frac{R^4}{z^4} e^{-cz^2} f(z)$$  \hspace{1cm} (23)

$$P(z) \equiv \frac{R^4}{z^4} e^{-cz^2}$$  \hspace{1cm} (24)

$$N(z) \equiv \frac{R^4}{z^4} e^{-cz^2} \frac{1}{f(z)}$$  \hspace{1cm} (25)

After some algebraic calculation, one can obtain,$$
LT = \frac{2}{y_h} \sqrt{1 - y^4_h \cosh^2 \eta} \int_1^\infty \frac{dy}{\sqrt{(y^4 e^a - 1)(y^4 - y^4_h)}}$$  \hspace{1cm} (26)
where \( a \equiv \frac{c}{\pi^2 T^2 y_h^2} (1 - \frac{1}{y^2}) \).

We consider Taylor expansion of \( e^a \) and choose second approximation which corresponds to first order of deformation parameter. Now, we explain some mathematical tools. From (26), we consider following integral,

\[
I = \int_{1}^{\infty} \frac{dy}{\sqrt{(y^4 e^a - 1)(y^4 - y^4_h)}},
\]

and Taylor expansion of \( e^a \) is:

\[
e^a = 1 + a + \frac{a^2}{2!} + ... + \frac{a^n}{n!} = \sum_{n=0}^{\infty} \frac{a^n}{n!},
\]

and also here we have

- \( n=0 \) corresponds to \( c = 0 \) or zeroth order of deformation parameter
- \( n=1 \) corresponds to \( c \) or first order of deformation parameter
- \( n=n \) corresponds to \( c^n \) or n’th order of deformation parameter

In this work we consider the first order of deformation parameter, so, \( e^a \approx 1 + a \), since \( a \gg 1 \) and also \( y^4 e^a \gg 1 \), the term 1 can be neglected in both cases. So the integral would be as

\[
I = \int_{1}^{\infty} \frac{dy}{\sqrt{(y^4 - y^2)(y^4 - y^4_h)}},
\]

From hypergeometric functions, we have,

\[
\int_{0}^{1} t^{a_2-1} (1-t)^{-\alpha_2-1} (1-z^k t)^{-\alpha_1} dt = B(\alpha_2, \beta_1 - \alpha_2) \, {}_2F_1^{k_1}[(\alpha_1, 1), (\alpha_2, k_2); \beta_1; z],
\]

\[
{}_2F_1^{k_1}[(\alpha_1, 1), (\alpha_2, k_2); \beta_1; z] = \sum_{n=0}^{\infty} \frac{(\alpha_1)_n \, B_{b,d}^{k_1}(\alpha_2 + k_2 n, \beta_1 - \alpha_1) \, z^n}{B(\alpha_2, \beta_1 - \alpha_2) \, n!}.
\]

If we take \( t = \frac{1}{y^2} \) the integral will be as,

\[
I = \frac{1}{2} \int_{0}^{1} t^{\frac{1}{2}} (1-t)^{-\frac{1}{2}} (1-t^2 y_h^4)^{-\frac{1}{2}} dt = \frac{1}{4} B\left(\frac{7}{2}, \frac{3}{2}\right) y_h^4.
\]
By using the equations (29)-(32) one can manage the corresponding problem. Also we note that in section 2 the integrals are formed with gaussian hypergeometric functions but in section 3 they don’t have gaussian representation, we refer the reader to Ref.[59]. Finally the equations (29)-(32) help us to obtain,

\[ L \sqrt{c} = 2 \sqrt{1 - y_h^4 \cosh^2 \eta} \int_1^\infty \frac{dy}{\sqrt{(y^4 - y^2)(y^4 - y_h^4)}} \]  

(33)

The representation of the hypergeometric function of this integral give us,

\[ L \sqrt{c} = 2 \sqrt{1 - y_h^4 \cosh^2 \eta} B(7/2, 3/2) y_h^4. \]  

(34)

So, the real part of potential \( ReV_{\bar{Q}Q} \) will be as,

\[ ReV_{\bar{Q}Q} = - \frac{\sqrt{\lambda c}}{\pi T} \int_1^\infty \frac{dy(y^4 - y_h^4 \cosh^2 \eta)(\frac{1}{2} - \frac{1}{y^2})}{\sqrt{(y^4 - y^2)(y^4 - y_h^4)}} \]  

- \[ \frac{\sqrt{\lambda c}}{\pi T}. \]  

(35)

We rewrite the above equation as,

\[ ReV_{\bar{Q}Q} = - \frac{\sqrt{\lambda c}}{\pi T} \left[ \frac{1}{8} B(\frac{3}{2}, \frac{1}{2}) y_h^4 - \frac{1}{8} B(\frac{7}{2}, \frac{3}{2}) y_h^8 \cosh^2 \eta \right. \]  

\[ - \frac{1}{4} B(\frac{5}{2}, \frac{1}{2}) y_h^4 + \frac{1}{4} B(\frac{9}{2}, \frac{5}{2}) y_h^8 \cosh^2 \eta \]  

\[ \left. - \frac{\sqrt{\lambda}}{\pi c} \right]. \]  

(36)

Now, we are ready to calculate the imaginary part of potential in case of \( \bar{M}_* > 0 \) we have following relation,

\[ \frac{ImV_{\bar{Q}Q}}{\sqrt{\lambda}} = - \frac{\pi T}{4 \sqrt{2} y_h} e^{-\alpha c^2} \sqrt{1 - y_h^4 \cosh^2 \eta} \]  

\[ \times \left[ \frac{2 c y_h^2}{\pi^2 T}(1 - y_h^4 \cosh^2 \eta) + 12 \right. \]  

\[ \left. \frac{2 c y_h^2}{\pi^2 T}(1 - y_h^4 \cosh^2 \eta) + 12 \right] - \frac{(1 - y_h^4 \cosh^2 \eta)}{2 - \frac{c y_h^2}{\pi^2 T}(1 - y_h^4 \cosh^2 \eta)}. \]  

(37)

And the condition \( ImV_{\bar{Q}Q} < 0 \) is satisfied. For \( \bar{M}_* < 0 \) as mentioned before \( ImV_{\bar{Q}Q} \approx 0 \).

We can see from (37) this expression is always negative as expected.

Following last procedure, we assume \( ReV_{\bar{Q}Q} = \sqrt{c_{\text{max}}} \) and \( ImV_{\bar{Q}Q} = \sqrt{c_{\text{max}}} \) to investigate behavior of them with respect to \( \eta \). The first one is scaled with \( T^2 \sqrt{\frac{2}{c}} \) and the second one with \( \sqrt{\lambda} \), notice that one should peruse \( ImV_{\bar{Q}Q} \) in variable \( T \). It means that graph should be fine
Figure 4: $L\sqrt{c}$ as a function of $y_h$ for different values of $\eta$. Here, also $Q\bar{Q}$ is oriented to the hot wind and first order of deformation parameter is contributed.

tuned with $T$.

Figure 4 shows albeit $y_h$ is between 0 and 1, $L\sqrt{c}$ is equal to zero in some values of $y_h$. It means approximately in region $0 < y_h < 0.2$, there is no proof for existence of meson. Reader may remember that $y_h$ is ratio of deepest position of the string in the bulk to event horizon. So, meson that is being described with an infinite string in the bulk, after $y_h \approx 0.2$ in a deformed space is visible. In spite of last sector, $ReV_{Q\bar{Q}}$ in figure 5 represent that $Q\bar{Q}$ feels the moving plasma for any value of $\eta$ and increases with increasing $\eta$, when first order of $c$ is contributed.

Imaginary part of potential for moving heavy quarkonia is more interesting. Because the reader can see from (37) one does not need to use any approximation for this relation. It means this is the “exact imaginary part of potential” for a deformed AdS. Similar to $AdS_5$ case, it decreases with increasing $\eta$. It means that thermal width is suppressed. With manipulating $T$ in graph, this behavior has no change with $\eta$. Or, there are same schema for all values of finetuing $T$ in the range. It means the thermal changes has no effect on thermal
Figure 5: Scaled real part of potential as a function of $\eta$, $Q\overline{Q}$ is oriented to the hot wind and first order of deformation parameter is contributed.

Figure 6: Scaled imaginary part of potential as a function of $\eta$, $Q\overline{Q}$ is oriented to the hot wind and deformation parameter is contributed.
width.

4 Conclusion

In this article, we have used the method [36] to investigate the real and imaginary parts of potential for moving heavy quarkonia in plasmas with two example of gravity duals. The first one was $AdS_5$ and the other was a deformed AdS. In both cases $Q\bar{Q}$ pair oriented perpendicularly to the hot wind. We have found that for the case deformation parameter is $c = 0$ the $Q\bar{Q}$ pair does not feel moving plasma for some values of $\eta$, but when first order of deformation parameter contributes, $ReV_{Q\bar{Q}}$ increases with increasing $\eta$ for all values of velocity. Also in deformed AdS meson is not visible in some regions of bulk. Finally we saw deformed AdS and $AdS_5$ have similar behavior of thermal width schematically.

It would be interesting that survey other orders of deformation parameter and effects of them on behavior of $QQ$ in $ReV_{Q\bar{Q}}$ sector, for that there are some complicated calculations.

The other interesting problem is instead of to use the soft wall model we use hyper violation metric background and discuss the moving mesons and investigate real and imaginary parts of potential. This problem with corresponding metric background for the moving meson in plasma media is in hand.

References

[1] J. M. Maldacena, Adv. Theor. Math. Phys.2, 231 (1998).

[2] J. M. Maldacena, Int. J. Theor. Phys. 1113 (1999),[arXiv: 9711200 [hep-th]] .

[3] S. S. Gubster, I. R. Klebanov and A. M. Polyakov, Phys. Lett. B428 , 105 (1998) [arXiv: 9802109 [hep-th]]

[4] E. Witten, Adv. Theor. Math. Phys. 2, 253 (1998), [arXiv: 9802150 [hep-th]]
[5] O. Aharony, S. S. Gubster, J. M. Maldacena, H. Ooguri and Y. Oz, Phys. Rept. 323, 183 (2000), [arXiv: 9905111[hep-th]].

[6] J. Erlich, E. Katz, D. T. Son, M A Stephanov, Phys.Rev.Lett. 95, 261602 (2005), [arXiv: 0501128[hep-ph]].

[7] K. Ghoroku, N. Maru, M. Tachibana and M. Yahiro, Phys. Lett. B633, 602 (2006).

[8] H. R. Grigoryan and A. V. Radyushkin, Phys. Lett. B650, 421 (2007), [arXiv: 0703069[hep-ph]].

[9] H. R. Grigoryan and A. V. Radyushkin, Phys. Rev. D76, 115007 (2007), [arXiv: 0709.0500[hep-ph]].

[10] E. Katz, A. Lewandowski and M. D. Schwartz, Phys. Rev. D74, 086004 (2006), [arXiv: 0510388[hep-ph]].

[11] J. Polchinski and M. J Strassler, Phys. Rev. Lett. 88, 031601 (2002),[arXiv: 0109174[hep-th]].

[12] L. Da Rold and A. Pomarol, Nucl. Phys. B721, 79 (2005), [arXiv: 0501218[hep-ph]].

[13] A. Karch, E. Katz, D. T. Son and M. A. Stephanov, Phys. Rev. D74, 015005 (2006), [arXiv: 0602229[hep-ph]].

[14] S. J. Brodsky, G. F. de Teramond and A. Deur, Phys. Rev. D81, 096010 (2010), [arXiv: 1002.3948[hep-ph]].

[15] G. F. de Teramond and S. J. Brodsky, AIP Conf. Proc.1296, 128 (2010), [arXiv:1006.2431[hep-ph]].

[16] W.D. Paula and T.Frederico, Phys. Lett. B693, 287291 (2010), [arXiv:0908.4282[hep-ph]].

[17] H. Forkel, M. Beyer and T. Frederico, JHEP0707, 077 (2007),[arXiv: 0705.1857 [hep-ph]].
[18] W. de Paula, T. Frederico, H. Forkel and M. Beyer, Phys. Rev. D79, 075019 (2009), arXiv:0806.3830[hep-ph].

[19] B. Galow, E. Megias, J. Nian and H. J. Pirner, Nucl. Phys. B 834, 330 (2010), [arXiv: 0911.0627[hep-ph]].

[20] J. Nian and H. J Pirner, Nucl. Phys. A833, 119 (2010), [arXiv: 0908.1330[hep-ph]].

[21] H. R. Grigoryan and A. V. Radyushkin, Phys. Rev. D76, 095007 (2007), [arXiv: 0706.1543[hep-ph]].

[22] H. Forkrl, Phys. Rev. D78, 025001 (2008), arXiv:0711.1179[hep-ph].

[23] H. J. Kwee and R. F. Lebed, Phys. Rev. D77, 115007 (2008), [arXiv: 0712.1811[hep-ph]].

[24] P. Colangelo, F. De Fazio, F. Jugeau and S. Nicotri, Phys. Lett. B652, 73 (2007), [arXiv: 0703316[hep-ph]].

[25] A. Vega and I. Schmidt, Phys. Rev. D79, 055003 (2009), [arXiv: 0811.4638[hep-ph]].

[26] A. Vega, I Schmidt, T Branz, T Gutsche and V E Lyubovitskij, Phys. Rev. D80, 055014 (2009), [arXiv: 0906.1220[hep-ph]].

[27] A. Vega and . Schmidt, Phys. Rev. D 82, 115023 (2010), arXiv:1005.3000[hep-ph].

[28] G. F. de Teramond and S. J. Brodsky, AIP Conf. Proc. 1257, 59 (2007), [arXiv: 1001.5193[hep-ph]].

[29] Z. Abidin and C. E. Carlson, Phys. Rev. D79, 115003 (2009), [arXiv: 0903.4818[hep-ph]].

[30] T. Branz, T. Gutsche, V. E. Lyubovitskij, I. Schmidt and A. Vega, Phys. Rev. D82, 074022 (2010), arXiv:1008.0268[hep-ph].
[31] A. Vega, I. Schmidt, T. Gutsche and V. E. Lyubovitskij, Phys. Rev. D83, 036001 (2011), [arXiv: 1010.2815[hep-ph]].

[32] M. Strickland, Phys. Rev. Lett.107, 132301 (2011) [arXiv:1106.2571[hep-ph]].

[33] M. Strickland and D. Bazow, Nucl. Phys. A879, 25 (2012) [arXiv:1112.2761[nucl-th]].

[34] M. Margotta, K. McCarty, C. McGahan, M. Strickland, and D. Yager-Elorriaga, Phys.Rev.D83, 105019 (2011), [arXiv:1101.4651[hep-ph]].

[35] G.Aarts, C. Allton, S. Kim, M. P. Lombardo, M. B. Oktay, S. M. Ryan, D. K. Sinclair and J. I. Skullerud, JHEP 1303, 084 (2013) [arXiv:1210.2903[hep-lat]].

[36] S. I. Finazzo and J. Noronha, [arXiv: 1406.2683[hep-th]].

[37] S. I. Finazzo and J. Noronha, JHEP 1311, 042 (2013) [arXiv:1306.2613[hep-ph]].

[38] J. Erlich, E. Katz, D. T. Son and M. A. Stephanov, Phys. Rev. Lett.95, 261602 (2005).

[39] G. F. de Teramond and S. J. Brodsky, Phys. Rev. Lett.94, 201601 (2005).

[40] L. Da Rold and A. Pomarol, Nucl. Phys. B721, 79 (2005).

[41] J. Babington, J. Erdmenger, N. J. Evans, Z. Guralnik and I. Kirsch, Phys. Rev. D69, 066007 (2004) [arXiv:0306018[hep-th]].

[42] M. Kruczenski, D. Mateos, R. C. Myers and D. J. Winters, JHEP0405 (2004) 041.

[43] T. Sakai and S. Sugimoto, Prog.Theor. Phys.113, 843 (2005) [arXiv:0412141[hep-th]].

[44] T. Sakai and S. Sugimoto, Prog. Theor. Phys.114, 1083 (2006) [arXiv:0507073[hep-th]].

[45] S. He, M. Huang, Q. S. Yan and Y. Yang, Eur.Phys.J.C.(2010)66:187, [arXiv:0710.0988[hep-ph]].

[46] A. Karch, E. Katz, D. T. Son and M. A. Stephanov, Phys. Rev. D 74, 015005 (2006) [arXiv:0602229[hep-ph]].
[47] O. Andreev and V. I. Zakharov, Phys.Rev. D74, 025023 (2006) [arXiv:0604204[hep-ph]].

[48] F. Zuo, Phys. Rev. D 82, 086011 (2010) [arXiv:0909.4240 [hep-ph]].

[49] G. F. de Teramond and S. J. Brodsky, [arXiv:0909.3900 [hep-ph]].

[50] J. P. Shock, F. Wu, Y. L. Wu and Z. F. Xie, JHEP 0703, 064 (2007).

[51] K. Ghoroku, M. Tachibana and N. Uekusa, Phys. Rev. D68, 125002 (2003) [arXiv:0304051[hep-th]].

[52] K. Ghoroku, N. Maru, M. Tachibana and M. Yahi ro, Phys. Lett. B 633, 602 (2006) [arXiv:0510334[hep-ph]].

[53] C. Csaki and M. Reece, JHEP 0705, 062 (2007) [arXiv:0608266[hep-ph]].

[54] U. Gursoy and E. Kiritsis, JHEP 0802, 032 (2008) [arXiv:0707.1324 [hep-th]].

[55] U. Gursoy, E. Kiritsis and F. Nitti, JHEP 0802, 019 (2008) [arXiv:0707.1349 [hep-th]].

[56] D. f. Zeng, Phys. Rev. D78, 126006 (2008) [arXiv:0805.2733 [hep-th]].

[57] H. J. Pirner and B. Galow, Phys. Lett. B 679, 51 (2009) [arXiv:0903.2701 [hep-ph]].

[58] S. He, M. Huang and Q. S. Yan, arXiv:1004.1880 [hep-ph].

[59] L. Minjie, arXiv:1302.2307v1 [math.CA]

[60] D. Li, S. He, M. Huang and Q. S. Yan, JHEP 1109, 041 (2011) [arXiv:1103.5389 [hep-th]].