Graviton and Radion Production at LHC: From pp and PbPb Collisions

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If the Planck scale is around a TeV in theories with large extra dimension, then gravitons should be produced in high energy hadronic collisions at the LHC. In this paper we compute the direct graviton production cross section in a pp and PbPb collision at LHC at $\sqrt{s_{NN}} = 14$ TeV and 5.5 TeV respectively. The graviton production cross section in a lead-lead collision is enhanced in comparison to a pp collision at LHC depending upon the minimum transverse energy of the jet $E^\text{min}_{T,jet}$ above which the graviton production cross sections are computed. For two extra dimensions and above $E^\text{min}_{T,jet} = 100, 500, 1000, 1500$ GeV the ratio of graviton production cross sections in a PbPb collision to that in a pp collision is found to be $2220, 400, 43, 2$. For four extra dimensions this ratio is found to be $470, 100, 10, 0.5$. In the Randall-Sundrum model the radion production cross section is also found to be enhanced in a lead-lead collision over that in a pp collision at LHC. The ratio of the radion production cross sections in a PbPb collision to that in a pp collision at LHC is found to be $1650, 460, 180, 67, 23, 1$ for radion of masses $100, 500, 1000, 1500, 2000, 3000$ GeV respectively.

I. INTRODUCTION

In the large extra dimension theories it has been proposed that while the standard model particles live in the usual 3+1 dimensional space, gravity can propagate in higher dimensional space. Furthermore it has been proposed that the size of the compactified extra dimensions can be very large. If this scenario is true then quantum gravity effects can be realized at scale much lower than the Planck mass, possibly at the TeV scale. This is a very interesting proposal because future collider experiments can probe the effects of the quantum gravity at the TeV scale. An important consequence of these ideas is that we should be able to produce gravitons in future collider experiments. When the extra dimension is compactified on a circle (for example) with size $R$ the gravitons propagating in the extra dimensions appear as a tower of massive states with almost continuous masses. The coupling of these gravitons with ordinary matter is determined by the gravitational interaction. Naively one would expect that the interaction of the graviton goes as the inverse powers of the Planck mass and hence very suppressed. However, the large phase-space of the compactified space enters into the scattering phase-space and the dependence of the Planck mass exactly cancels. Finally one has scattering cross sections which depend on the TeV scale Planck mass and hence can be measured at the collider experiments.

The interaction of graviton with the partons is obtained from the d-dimensional graviton interaction lagrangian:

$$\mathcal{L} = -\frac{1}{M_P} G^{(n)}_{\mu\nu} T^{\mu\nu}. \quad (1)$$

In the above equation $T^{\mu\nu}$ is the Yang-Mills energy momentum tensor with quark parts taken into account and $G^{(n)}_{\mu\nu}$ is the graviton with Kaluza-Klein mode $n$ which arises because of the compactified extra dimension. $M_P$ is the TeV scale Planck mass. The Feynman rules for for quark, gluon interaction with the graviton can be obtained from the above equation. For direct graviton production in the hadronic collisions at LHC we consider the $2 \rightarrow 2$ $(ij \rightarrow kG)$ partonic level collisions where $i, j, k = q(\bar{q})g$ and $G$ is the graviton. The final state quark or gluon (jet) is accompanied by a graviton $G$. The graviton has Kaluza-Klein mode $n$ and we must sum over $n$. However, for not too large extra dimensions the width of the mass splitting is very small and the gravitons are considered as having continuous mass distribution which has to be integrated to obtain inclusive graviton-jet production cross section. As the final state graviton interacts very weakly with the ordinary matter (detector), the emission gives rise to missing transverse energy as signatures of graviton production.

In the 5-dimensional Randall-Sundrum (RS) model the extra dimension is a single $S^1/Z_2$ orbifold, in which two three-branes of opposite tensions reside at the two fixed points ($\phi=0$ and $\phi = \pi$) and a cosmological constant in the bulk serves as the source of five-dimensional gravity. In this case the extra dimension is small, but the background metric is not flat. The scalar massless radion field $b(x)$ has been introduced by considering the metrics of the form:

$$ds^2 = e^{-2m_0|y|b(x)} g_{\mu\nu}(x) dx^\mu dx^\nu - b^2(x) dy^2 \quad (2)$$

where $y$ is the fifth coordinate and $g_{\mu\nu}(x)$ is the four-dimensional graviton. The radius of the extra dimension is associated with the vacuum expectation value of the massless four dimensional radion field. As this modulus field has zero potential the size of the extra dimension is not determined by the dynamics of the model. A mechanism of radion stabilization was proposed which arises classically from the presence of a bulk scalar field propagating in the background solution of the metric which generates the required potential to stabilize the
radion field $\mathcal{F}$. The minimum of the potential can be arranged to solve the hierarchy problem without fine tuning of parameters. As a consequence the radion gets a mass which is likely to be lighter than the Kaluza-Klein modes of any bulk field $\mathcal{F}$. The mass of the radion is $\sim \text{TeV}$ and the detection of this radion at collider experiments will be the first signature of RS model and stabilization mechanism.

Based on these ideas there have been a number of papers which calculate the direct graviton production and radion production in pp collisions at $\sqrt{s} = 14$ TeV at LHC and at other experiments such as in $p\bar{p}$ collisions at Tevatron and at $e^+e^-$ colliders. The aim of this paper is to compute the graviton and radion production cross section in a lead-lead collision at LHC where it is expected that the graviton and small mass radion production cross section should be much larger than that in a pp collision at LHC. This is similar to the black hole and string ball production at LHC where it is shown that the small mass black hole and string ball production cross section is much higher in a PbPb collision than in a pp collision at LHC. At present Relativistic Heavy Ion Collider (RHIC) at BNL collide two gold nuclei (to produce quark-gluon plasma) at $\sqrt{s_{NN}} = 200$ GeV, which is insufficient to probe any TeV scale physics, such as production of graviton and radion at TeV scale Planck mass. In order to create TeV scale particles the center of mass energy of two partons must be larger than TeV which is not the case at RHIC. The future collider at LHC will collide two Lead nuclei at $\sqrt{s_{NN}} = 5.5$ TeV in addition to pp collisions at $\sqrt{s} = 14$ TeV. As Lead nuclei at high energy consists of many more partons than proton, the total cross section is expected to be much larger in a PbPb collision than in a pp collision at the same center of mass energy. The larger production cross section in case of a PbPb collision comes from larger number of partonic collisions in comparison to a pp collision. The total center of mass energy of the PbPb system is $5.5 \times 208 = 1144$ TeV which is much larger than the $14$ TeV total center of mass energy of the pp system. However, as pp collision is at $\sqrt{s} = 14$ TeV and PbPb collision is at $\sqrt{s_{NN}} = 5.5$ TeV the total cross section in a PbPb collision is not equal to $\sim 208 \times 208$ times larger than that of the cross section in a pp collision. The question of shadowing and saturation of parton distribution function need to be addressed in case of large nuclei collisions at ultra high energy such as in the case of PbPb collisions at LHC. In this paper we will present detailed calculation of the direct graviton and radion production cross section in PbPb collisions and will make comparison with that in pp collisions at LHC.

The paper is organized as follows. In section II and III we present the partonic level calculations of the graviton and radion production cross sections in hadronic collisions. In section IV we present the results for pp, PbPb collisions at LHC and conclude in section V.

## II. GRAVITON PRODUCTION AT LHC

The differential cross section for the production of direct graviton plus a single jet in hadron-hadron (A-B) collisions at zero impact parameter is given by:

$$\frac{d^4\sigma_{AB \rightarrow j + G}}{d^3p_{T,j} \, dy_{G}} = 2p_T m_{G}^{d-1} \frac{\Omega_{d-1} M_P^2}{M_{d}^{d-2}} \sum_{i,j} F_{i/A}(x_1, Q^2) F_{j/B}(x_2, Q^2) \frac{d\sigma_{ij \rightarrow kG}}{dt} \frac{d \Omega_{ij}}{d \omega}.$$  \hspace{1cm} (3)

Here $F_{i/A}(x_1, Q^2)$ and $F_{j/B}(x_2, Q^2)$ are the parton structure functions of the hadron $A(B)$ with $x_1$ and $x_2$ being the longitudinal momentum fractions of the parton inside the hadron $A(B)$. $Q$ is the momentum scale at which the structure function is evaluated, $m_G$ is the graviton mass, $M_P$ is the TeV scale Planck mass, $M_d$ is the Planck mass and $p_T$ is the transverse momentum of the graviton (or jet). $d$ is the number of extra dimension and $\Omega_{d-1}$ is the surface of the unit-radius sphere in $d$ dimensions. $\frac{d\sigma_{ij \rightarrow kG}}{dt}$ is the partonic level differential scattering cross section for the process $ij \rightarrow kG$ where $i, j, k = q, \bar{q}, g$ and $G$ is the graviton. The partonic level differential cross sections for the processes: $ij \rightarrow kG$ are given by:

$$\frac{d\sigma_{q\bar{q} \rightarrow gG}}{dt} = \frac{\alpha_s}{36M_P^2} \frac{s}{t(m_{G}^2 - s - t)} \left[ \frac{-4\hat{t}}{s} \left( 1 + \frac{i}{s} \right) \left( 1 + 2\frac{i}{s} \right) + \frac{2\hat{t}^2}{s^2} \right] + \frac{m_G^2}{s} \left( 1 + 4\frac{i}{s} \right),$$  \hspace{1cm} (4)

for the $q\bar{q} \rightarrow gG$ process:

$$\frac{d\sigma_{qg \rightarrow qgG}}{dt} = \frac{\alpha_s}{96M_P^2} \frac{s}{t(m_{G}^2 - s - t)} \left[ \frac{-4\hat{t}}{s} \left( 1 + \frac{i}{s} \right) \left( 1 + 2\frac{i}{s} \right) + \frac{m_G^2}{s} \left( 1 + \frac{i}{s} \right) \left( 1 + 4\frac{i}{s} \right) \right] + \frac{m_G^2}{s^3} \left( 1 + \frac{i}{s} \right),$$  \hspace{1cm} (5)

for the $qg \rightarrow qgG$ process and:

$$\frac{d\sigma_{gg \rightarrow gG}}{dt} = \frac{3\alpha_s}{16M_P^2} \frac{s}{t(m_{G}^2 - s - t)} \left[ 1 + \frac{2\hat{t}}{s} + \frac{3\hat{t}^2}{s^2} \right] + \frac{\hat{t}^3}{s^4} \left( 1 + \frac{3\hat{t}}{s} \right) + \frac{m_G^2}{s^2} \left( 1 + \frac{i}{s} \right) \left( 1 + \frac{4\hat{t}}{s} \right) + \frac{m_G^2}{s^3} \left( 1 + \frac{i}{s} \right),$$  \hspace{1cm} (6)

for the $gg \rightarrow gG$ process. In the above expression: $\hat{s} = (p_i + p_j)^2$ and $\hat{t} = (p_i - p_G)^2$. 


As the graviton mass splitting is very small in the flat extra dimension models the mass $m_G$ of the graviton is treated as continuous variable rather than the discrete mass level in the extra dimension. Therefore the mass $m_G$ is integrated out in eq. (3) in order to obtain inclusive cross section in hadronic collisions at LHC. As the total cross section is infrared divergent we compute the total inclusive cross section above certain transverse momentum of the jet $p_{T,jet} = E_{T,jet}$. The factorization and re-normalization scale appearing in $F_{i/A}(x_1, Q^2)$ ($F_{j/B}(x_2, Q^2)$) and $\alpha_s(Q^2)$ respectively, are taken to be at $Q^2 = M_T^2 = m^2_G + p_T^2$.

III. RADION PRODUCTION AT LHC

The interaction of the radion ($\phi$) with the standard model particles is given by:

$$\mathcal{L} = \frac{\phi}{\lambda_0} T^{\mu}_{\nu}(SM)$$

where the strength of the coupling of the radion to the standard model particles $\frac{\phi}{\lambda_0}$ is of order of $\sim 1$/TeV. In the above equation $T^{\mu}_{\nu}(SM)$ is the trace of the SM energy-momentum tensor:

$$T^{\mu}_{\nu} = \sum_i m_i \bar{f} f - 2m_W W^{\mu} W^{-\nu} - m_Z^2 Z^{\mu} Z^{\nu} + (2m_h^2 h^2 - \partial_{\mu} h \partial^{\nu} h) + \ldots$$

where $f$ is fermion and $h$ is Higgs boson. For the coupling of the radion to a pair of gluons comes from two parts: 1) contributions from one-loop diagrams with the top quark (and W) in the loop and 2) from the trace anomaly [20]:

$$T^{\mu}_{\nu}(SM)^{anom} = \sum_a \frac{\beta_{QCD}}{2g_s} F^{\mu\nu}_a F^{a\mu\nu}_a.$$ 

Including the one-loop top quark and trace anomaly contributions the effective coupling of a radion and two gluons $\phi gg$ is given by:

$$\frac{\delta^{ab}\alpha_s}{2\pi\lambda_0} [7 + \frac{4M_t^2}{2p_1 \cdot p_2} (1 - \frac{4M_t^2}{2p_1 \cdot p_2}) g (\frac{4M_t^2}{(p_1 + p_2)^2})] \times |p_1 \cdot p_2 g_{\mu\nu} - p_2 \mu p_1 \nu|$$

where $M_t$ is the mass of the top quark, $p_1$, $p_2$ are the momentum of the incoming gluons and

$$g (\frac{4M_t^2}{(p_1 + p_2)^2}) = \left[ \sinh^{-1} (\sqrt{\frac{(p_1 + p_2)^2}{2M_t^2}}) \right]^2$$

if $(p_1 + p_2)^2 \leq 4M_t^2$

$$= \frac{1}{4} \left[ \ln (\sqrt{(p_1 + p_2)^2 + \sqrt{(p_1 + p_2)^2 - 4M_t^2}}) - i\pi \right]^2$$

if $(p_1 + p_2)^2 > 4M_t^2$.

As the dominant radion ($\phi$) production mechanism at pp collisions is given by the gluon fusion process

$$gg \rightarrow \phi$$

we will consider the gluon fusion process in this paper. The partonic level cross section for the gluon fusion process is given by [13]:

$$\sigma_{gg\rightarrow \phi}(s) = \frac{\alpha_s^2}{256\pi\lambda_0^2} \times [7 + \frac{4M_t^2}{s} [1 + (1 - \frac{4M_t^2}{s}) g (\frac{4M_t^2}{s})]^2]$$

where $g (\frac{4M_t^2}{s})$ is given by eq. (11) with $s = (p_1 + p_2)^2$ being the parton level center of mass energy. Convoluting with the gluon distribution function, the radion production cross section in the central collision of two hadrons A and B is given by:

$$\sigma_{AB\rightarrow \phi}(s) = \int dx_1 \int dx_2 f_{g/A}(x_1, Q^2) f_{g/B}(x_2, Q^2) \delta (\hat{s}_M - M_\phi^2) \hat{s} \sigma_{gg\rightarrow \phi}(\hat{s})$$

For nuclear collisions at very high energy the calculation is similar to that of the jet production in AA collisions at RHIC and LHC [21]. The parton distribution function inside a large nucleus is given by:

$$R_{A/N}(x_1, Q^2) = \frac{f_{A/N}(x_1, Q^2)}{A f_{A/N}(x_1, Q^2)}$$

where $f_{A/N}(x_1, Q^2)$ and $f_{A/N}(x_1, Q^2)$ are the parton distribution functions inside the free nucleus and free nucleon respectively. The NMC and EMC experiments show that $R_{A/N}(x_a, Q^2) \neq 1$ for all values of $x$. In fact there is a strong shadowing effect ($R_{A/N}(x_a, Q^2) < 1$) for much smaller values of $x$ ($x < 0.01$). However, for TeV scale physics the shadowing effects should not be important. This is because we may not probe the low $x$ physics as the scale $Q$ in our calculation is at least a TeV. For $Q = 1$ TeV the average value of Bjorken $x$ we probe is: $x_{av} = \frac{1}{2Q^2}$ which is very large. Even if we take the minimum transverse energy $E_{T,jet}$ or radion mass $M_\phi$ to be 100 GeV in our calculation this corresponds to the minimum average $x$ value $x_{av}^{min} = \frac{1}{2s}$ where the shadowing effects are not very large for $Q=100$ GeV as can be seen from Fig. 1. In Fig. 1 we have used the
EKS08 parametrization [2] for gluon shadowing effects at high energy. It can be seen that as the scale $Q$ becomes higher the shadowing effects become weaker. The present shadowing analysis [22,23] do not cover the factorization scale $Q$ up to (and above) 1 TeV. For this reason, and as shadowing effects are not important for TeV scale physics we will use the unshadowed parton distribution function $R_A(x, Q^2) = 1$ in this paper. Similarly the saturation of gluons at LHC is not important for TeV scale physics as gluon saturation occurs at low value of $x$ (equivalent to $Q \sim 2$ GeV [24]) which is not covered in the TeV scale physics calculations.

IV. RESULTS AND DISCUSSIONS

In this section we will compute the cross section for graviton and radion production at LHC both in pp and PbPb collisions at $\sqrt{s}^{NN} = 14$ and 5.5 TeV respectively. As the dominant radion production cross section comes from $gg \rightarrow \phi$ fusion process which is a $2 \rightarrow 1$ process, the total cross section is finite and depend on the mass of the radion. However, the total cross section for the graviton production process: $AB \rightarrow jet + graviton$ is a $2 \rightarrow 2$ process and is divergent at zero transverse momentum of the final state jet. We present the results of graviton production total cross section above certain transverse momentum of the jet $p_{T,jet} = E_{T,jet}$. Rapidity range for graviton production computation is taken to be $|y_{jet,G}| < 3$. We use recent CTEQ6 [25] parton structure function in our calculation. This structure function covers the range of $Q$ up to 10 TeV.

In Fig. 2a we present the cross section for graviton + jet production as a function of minimum transverse energy of the jet for a pp collision at $\sqrt{s} = 14$ TeV at LHC. As the dependence of cross section on number of extra dimensions in pp collisions at LHC is studied in more details in Figs. 3 and 4 we will choose only one value of number of extra dimension ($d=2$) in case of the pp collision for the comparison purpose. All the curves in Fig. 2a correspond to $d=2$. The minimum transverse energy of the jet is chosen to be from 100 GeV to 2 TeV in our calculation. The solid, dotted, dashed, dot-dashed lines correspond to Planck mass $M_{\phi} = 2, 3, 4, 5$ TeV respectively. In Fig. 2b we present the cross section for graviton + jet production as a function of minimum transverse energy of the jet for a PbPb collision at $\sqrt{s} = 5.5$ TeV at LHC. The solid and dotted lines correspond to $M_{\phi} = 2$ and 3 TeV respectively for number of extra dimensions $d=2$ and the dashed and dot-dashed lines correspond to $M_{\phi} = 2$ and 3 TeV respectively but for $d=4$.

A comparison with Fig. 2a for the case of pp collision for $d=2$ shows that the graviton production is much larger in a PbPb collision than in a pp collision at LHC. Above $E_{T,jet} = 100$ GeV the graviton production in a PbPb collision is 2220 times larger than that in a pp collision at LHC. This number is independent of the Planck mass as Planck mass cancel in the ratio. This can be seen in Fig. 4a where the ratio of total cross section in a PbPb collision to a pp collision at LHC is plotted as a function of minimum transverse energy of the jet $E_{T,jet}$. Above $E_{T,jet} = 500, 1000, 1500$ GeV this ratio is 400, 43, 2 respectively in case of the number of extra dimension $d=2$. For $d=4$ this ratio is 470, 100, 0.5 above the minimum transverse energy of the jet $E_{T,jet} = 100, 500, 1000, 1500$ GeV which can also be seen from Fig. 4a.

One can observe that the graviton production is much more enhanced in a PbPb collision than in a pp collision for minimum transverse energy of the jet $E_{T,jet} = 1.5$ TeV. Hence PbPb collisions at LHC can be considered as graviton production factory for minimum transverse energy of the jet up to $E_{T,jet} = 1.5$ TeV and pp collisions at LHC can be considered as graviton production factory for minimum transverse energy of the jet above $E_{T,jet} = 1.5$ TeV. Hence pp and PbPb collisions at LHC will provide the best opportunities to find the possible existence of extra dimensions.

In Fig. 3a we present the radion production cross section from the gluon fusion process in a pp collision at LHC as a function of radion mass $M_{\phi}$. Different lines are for different values of $\lambda_{\phi}$, the strength of the radion coupling to the standard model particles. The solid, dashed, dotted lines correspond to $\lambda_{\phi} = 1, 2, 3$ TeV respectively. The radion production is described in a 5-d theory hence there is no extra dimension dependence on the cross section as was in the case of graviton production. In Fig. 3b we present the radion production cross section from the gluon fusion process in a PbPb collision at LHC as a function of radion mass $M_{\phi}$. The solid, dashed, dotted lines correspond to $\lambda_{\phi} = 1, 2, 3$ TeV respectively.

As can be seen from Fig. 3 the radion production in a PbPb collision is much higher than in a pp collision at LHC. For radion of mass $M_{\phi} = 100$ GeV the radion production cross section in a PbPb collision is 1650 times larger than that in a pp collision at LHC. In Fig. 4b we present the ratio of the radion production cross section in a PbPb collision to that in a pp collision at LHC as a function of radion mass. The ratio is 1650, 460, 180, 67, 23 and 1 for radion of masses 100, 500, 1000, 1500, 2000 and 3000 GeV respectively. This ratio is independent of radion coupling strength $\lambda_{\phi}$. It can be observed that the radion cross section is much larger in a PbPb collision than in a pp collision even up to radion mass of 3 TeV. Therefore PbPb collisions at LHC can be considered as radion production factory for radion masses up to 3 TeV and pp collisions at LHC can be considered as radion production factory for radion masses above 3 TeV.
V. CONCLUSION

If the Planck scale is around a TeV in theories with large extra dimension, then gravitons and radions should be produced in high energy hadronic collisions at the LHC. In this paper we have computed the direct graviton and radion production cross sections in a pp and PbPb collision at LHC at $\sqrt{s_{NN}} = 14$ and 5.5 TeV respectively. The direct graviton (plus jet) production cross section in a PbPb collision is enhanced in comparison to a pp collision at LHC depending upon the minimum transverse energy $E_{T,\text{jet}}^{\min}$ of the jet. For two extra dimensions and above $E_{T,\text{jet}}^{\min} = 100, 500, 1000, 1500$ GeV the ratio of graviton production cross section in a PbPb collision to that in a pp collision is found to be 2220, 400, 43, 2. For four extra dimensions this ratio is found to be 470, 100, 10, 0.5. The radion production cross section is also found to be enhanced in a PbPb collision than in a pp collision at LHC. The ratio of the radion production cross section in a PbPb collision to that in a pp collision at LHC is found to be 1650, 460, 180, 67, 23 and 1 for radion of mass 100, 500, 1000, 1500, 2000 and 3000 GeV respectively. Hence PbPb (pp) collisions at LHC can be considered as graviton production factory up to (above) the minimum transverse momentum of the jet $\sim 1.5$ TeV. Similarly PbPb (pp) collisions at LHC can be considered as radion production factory for radion masses up to (above) 3 TeV. Hence pp and PbPb collisions at LHC will provide the best opportunities to find the possible existence of extra dimensions.

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FIG. 1: The gluon shadowing at LHC and TeV scale physics. There is no significant impact of gluon shadowing on TeV scale physics as TeV scale physics do not correspond to small Bjorken $x$. 
Graviton Production at LHC
pp Collisions, \( \sqrt{s} = 14 \text{ TeV} \)

Graviton Production at LHC
PbPb Collisions, \( \sqrt{s} = 5.5 \text{ TeV} \)

Radion Production at LHC
pp Collisions, \( \sqrt{s} = 14 \text{ TeV} \)

Radion Production at LHC
PbPb Collisions, \( \sqrt{s} = 5.5 \text{ TeV} \)

FIG. 2a: The total cross section for graviton production in a pp collision at \( \sqrt{s} = 14 \text{ TeV} \) at LHC as a function of minimum transverse energy of the jet.

FIG. 2b: The total cross section for graviton production in a PbPb collision at \( \sqrt{s} = 5.5 \text{ TeV} \) at LHC as a function of minimum transverse energy of the jet.

FIG. 3a: The total cross section for radion production in a pp collision at \( \sqrt{s} = 14 \text{ TeV} \) at LHC as a function of radion mass from the gluon fusion process.

FIG. 3b: The total cross section for radion production in a PbPb collision at \( \sqrt{s} = 5.5 \text{ TeV} \) at LHC as a function of radion mass from the gluon fusion process.
FIG. 4a: The ratio of the total cross section for graviton production in a PbPb collision at $\sqrt{s^N_N} = 5.5$ TeV to a pp collision at $\sqrt{s} = 14$ TeV at LHC as a function of minimum transverse energy of the jet.

FIG. 4b: The ratio of the total cross section for radion production in a PbPb collision at $\sqrt{s^N_N} = 5.5$ TeV to a pp collision at $\sqrt{s} = 14$ TeV at LHC as a function of radion mass from the gluon fusion process.