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Higgs pair production in association with a vector boson at e^+e^- colliders in theories of higher dimensional gravity

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Abstract

In this note, we study the contribution of virtual Kaluza-Klein excitations (both spin-0 and 2) of gravitons in the process $e^+e^- \to HHZ$ and $e^+e^- \to HH\gamma$ at future linear collider (NLC) in ADD model. We find that the virtual exchange KK gravitons can modify the cross-section $\sigma(e^+e^- \to HHZ)$ significantly from its Standard Model value and will allow the effective string scale to be probed up to 6.6 TeV. The second process is absent at the tree level in the standard model, and can therefore be used to put limits on the effective string scale of 7.4 TeV.

In this note [1] we will consider the process $e^+e^- \to HHZ$ and $e^+e^- \to HH\gamma$ to study the effect of virtual gravitons in the scenario of large extra dimensions and TeV scale gravity proposed by Arkhani-Hamed, Dimopoulos and Dvali, better known as ADD model [2, 3]. This new model has several interesting phenomenological consequences, which can be tested at present and future colliders [4, 5]. The effect of these new interactions can be observed either through production of real gravitons, or through the exchange of virtual gravitons in various processes [5, 6, 7].

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1 $e^+e^- \to HHZ$

In this section we study the additional contribution of virtual exchange of spin 2 and 0 graviton modes in models of large extra dimensions to the Higgs pair production in association with Z. In the standard model, the process $e^+e^- \to HHZ$ has been studied as a means of determining HHH couplings. The standard model amplitudes and polarized cross-sections are given in the Ref.[8]. In our analysis however, we shall use unpolarized beams.

In Figure 1, we represent the total cross-section for $M_H = 120$ GeV and $n = 3$ as a function of machine energy for three different values of $M_S = 3.5, 4.5$ and 5.5 TeV. The dashed line represents the standard model prediction. It is obvious from this Figure, that at energies around 3 TeV, the graviton contribution is enormous, if M_S is small (3.5 TeV); however, a discernible difference exists even when $M_S = 5.5$ TeV.

In Figure 2, we represent the fractional deviation $R = \frac{|\sigma(M_S)-\sigma_{SM}|}{\sigma_{SM}}$ as a function of M_S for two values of center of energies, 500 GeV (dashed line), and 1 TeV (solid line), where, $\sigma(M_S)$ is obtained from coherent sum of ADD and standard model amplitudes. The different choices of extra dimensions (n) are shown along each curve. It is very clear from this Figure, that higher the machine energy, larger is the deviation from the standard model. We consider that more than 10% deviation ($R = 0.1$) from the standard model prediction with an integrated luminosity $\mathcal{L}$ of 2ab^{-1} will be able to provide reasonable evidence of low-scale gravity. This argument is based on the result obtained in Ref.[9]. In our analysis we use the error of (10%) on the cross-section measurement (as shown in Ref [9]) to determine 5σ discovery limit on M_S with the same integrated luminosity of 2 ab^{-1}.

In the Table 1, we display the 5σ discovery limits on M_S as a function of e^+e^- center of mass energy ($\sqrt{s}$), number of extra-dimensions (n) and integrated luminosity.

2 $e^+e^- \to HH\gamma$

For the completeness of our study, in this section we discuss the production of $HH\gamma$ at e^+e^- collider through the virtual exchange of spin-2 and spin-0 KK gravitons. The scalar pair production at e^+e^- collider in the models of large extra-dimensions has been studied [10]. We impose the following identification criteria for the photon:

$$E_\gamma > 10 \text{ GeV} \tag{1}$$

$$|\cos\theta_\gamma| < 0.98 \tag{2}$$

$\sqrt{s}$	M_S in GeV			
TeV	$n = 3$	4	5	6
0.5	921	769	697	653
1.0	1998	1811	1685	1593
3.0	6598	6036	5634	5332

Table 1: 5σ limit on M_S assuming an integrated luminosity of 2 ab^{-1} for different center of mass energies ($\sqrt{s}$). n is the number of extra dimensions.

where, θ_γ defines the photon angle with the e^- beam direction. This angular cut on the photon removes the collinear divergence. These 'acceptance' cuts are more-or-less the basic ones. Though further selection cuts will become appropriate when a more detailed analysis is done, it suffices for our analysis, which is a preliminary study.

In Figure 3, we represent the total cross-section for $M_H = 120$ GeV and $n = 3$ as a function of machine energy for three different values of $M_S = 3.5, 4.5$ and 5.5 TeV. For a given M_S, the cross-section shows a marked increase with energy, depicting the well-known feature of gravitational interaction.

To estimate the possible 5σ discovery limit on the scale M_S with an integrated luminosity of 2ab^{-1}, we only consider the $ZH\gamma$ as the main source of standard model background. We estimate this background by using the CompHEP [11]. In Table 2 we display such discovery limits on M_S for different machine energies and extra-dimensions. As expected the strongest limit appears for $\sqrt{s} = 3$ TeV and for $n = 3$.

$\sqrt{s}$	M_S in GeV			
TeV	$n = 3$	4	5	6
0.5	1557	1175	993	883
1.0	2847	2154	1834	1637
3.0	7383	5673	4866	4383

Table 2: 5σ discovery limit on M_S assuming an integrated luminosity of 2 ab^{-1} for different center-of-mass energies ($\sqrt{s}$). n is the number of extra dimensions.

3 Conclusions

In this note we have studied the implications of KK graviton contribution to the processes $e^+e^- \to HHZ$ and $e^+e^- \to HH\gamma$. The spin-2 and spin-0 mode of KK gravitons contribute to these processes substantially. However, the existence of low-energy quantum gravity may be discovered through more direct channels as studied by several groups. Nevertheless, these process will be an independent confirmation for such a discovery.

4 Acknowledgments

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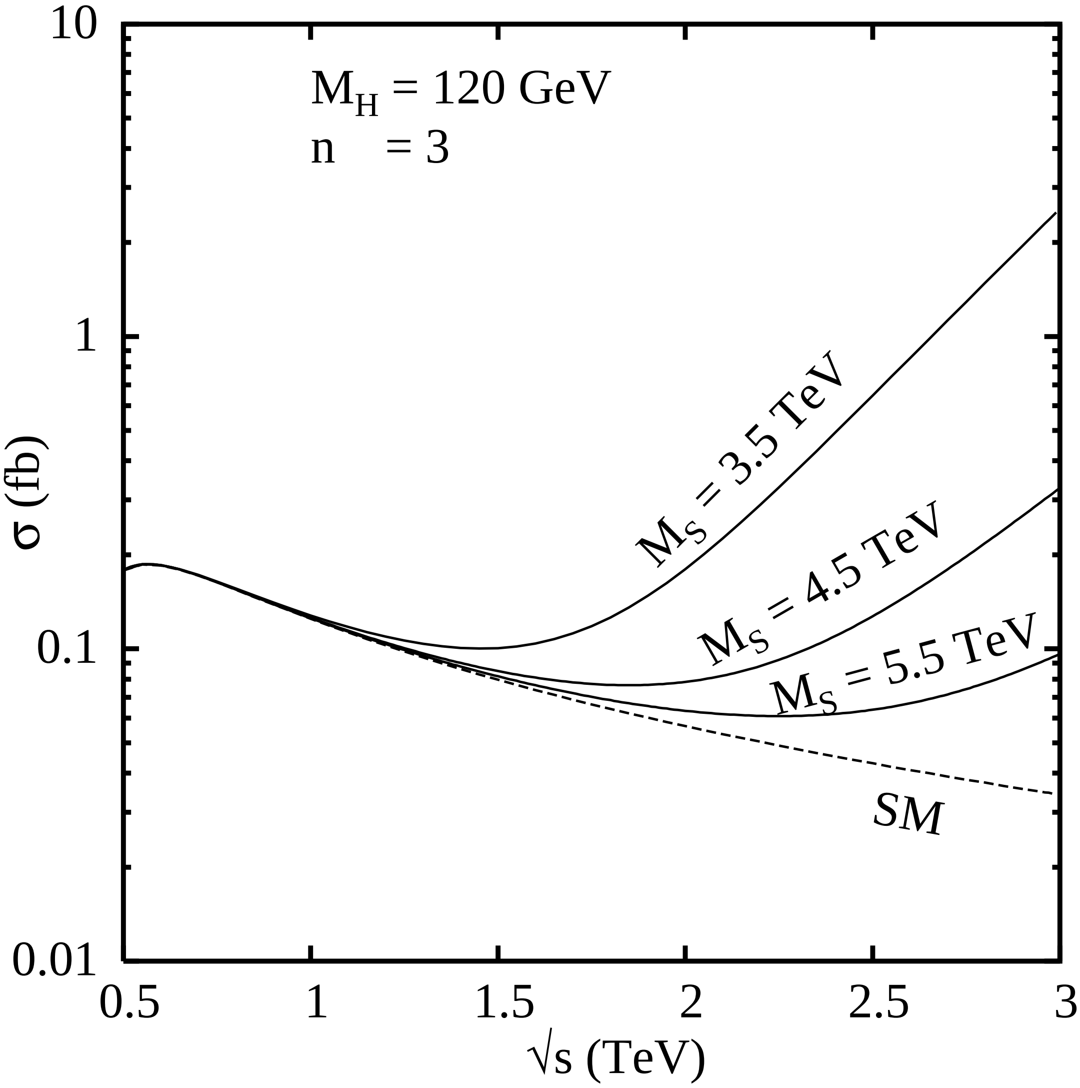

Figure 1: Variation of the cross-section (fb) for HHZ production with machine energy. The solid curves correspond to the ADD predictions for $M_S = 3.5, 4.5$ and 5.5 TeV and $n = 3$, while the dashed line represents only the standard model contributions. The Higgs mass is set to 120 GeV.

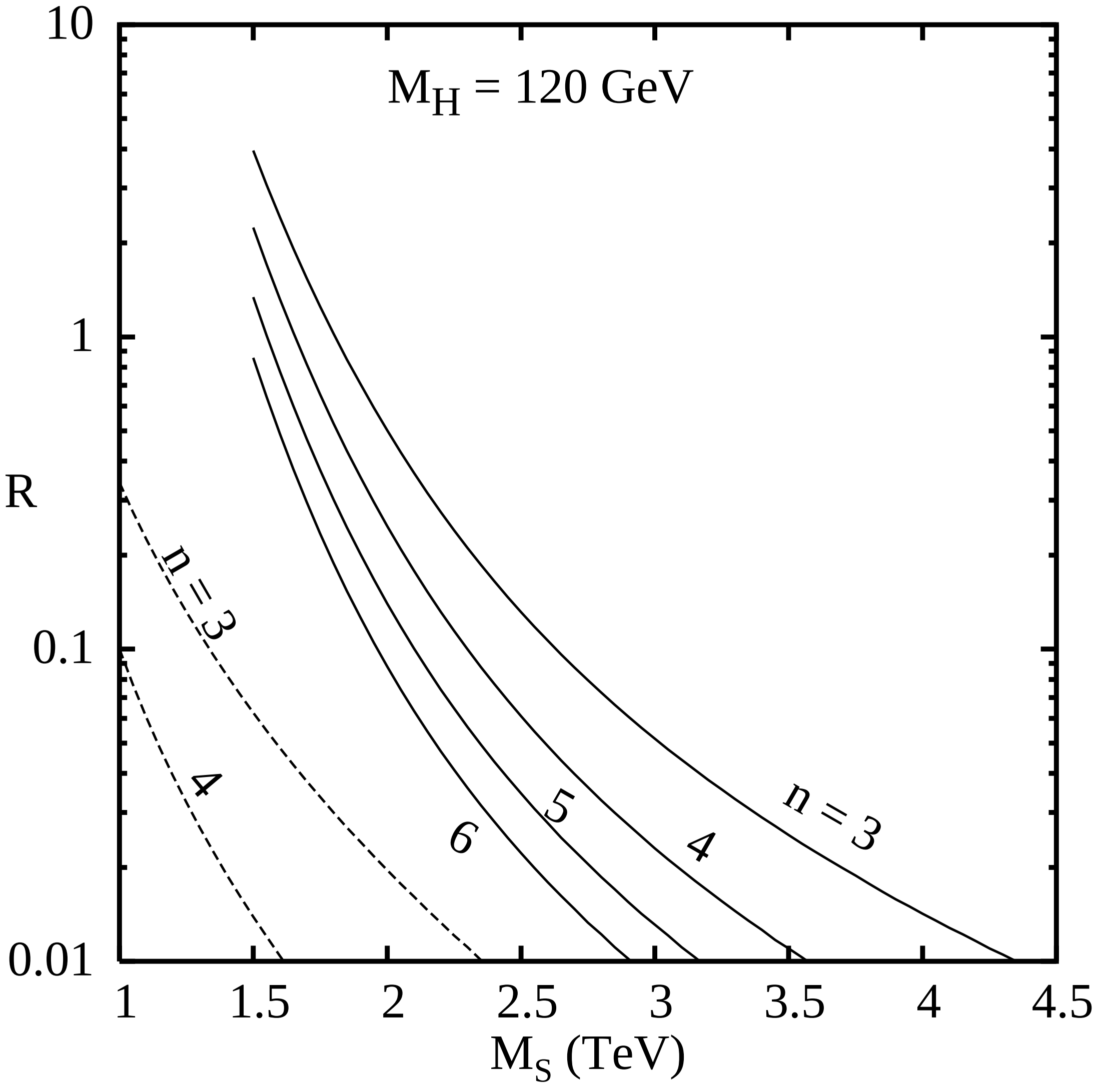

Figure 2: The fractional deviation R(defined in the text) of the cross-section for $e^+e^- \rightarrow HHZ$ from the standard model prediction as a function of M_S for different choices of extra dimensions as shown along the curves. The solid and dashed curves correspond to $\sqrt{s} = 1$ TeV and 0.5 TeV NLC. The Higgs mass is same as Figure 1.

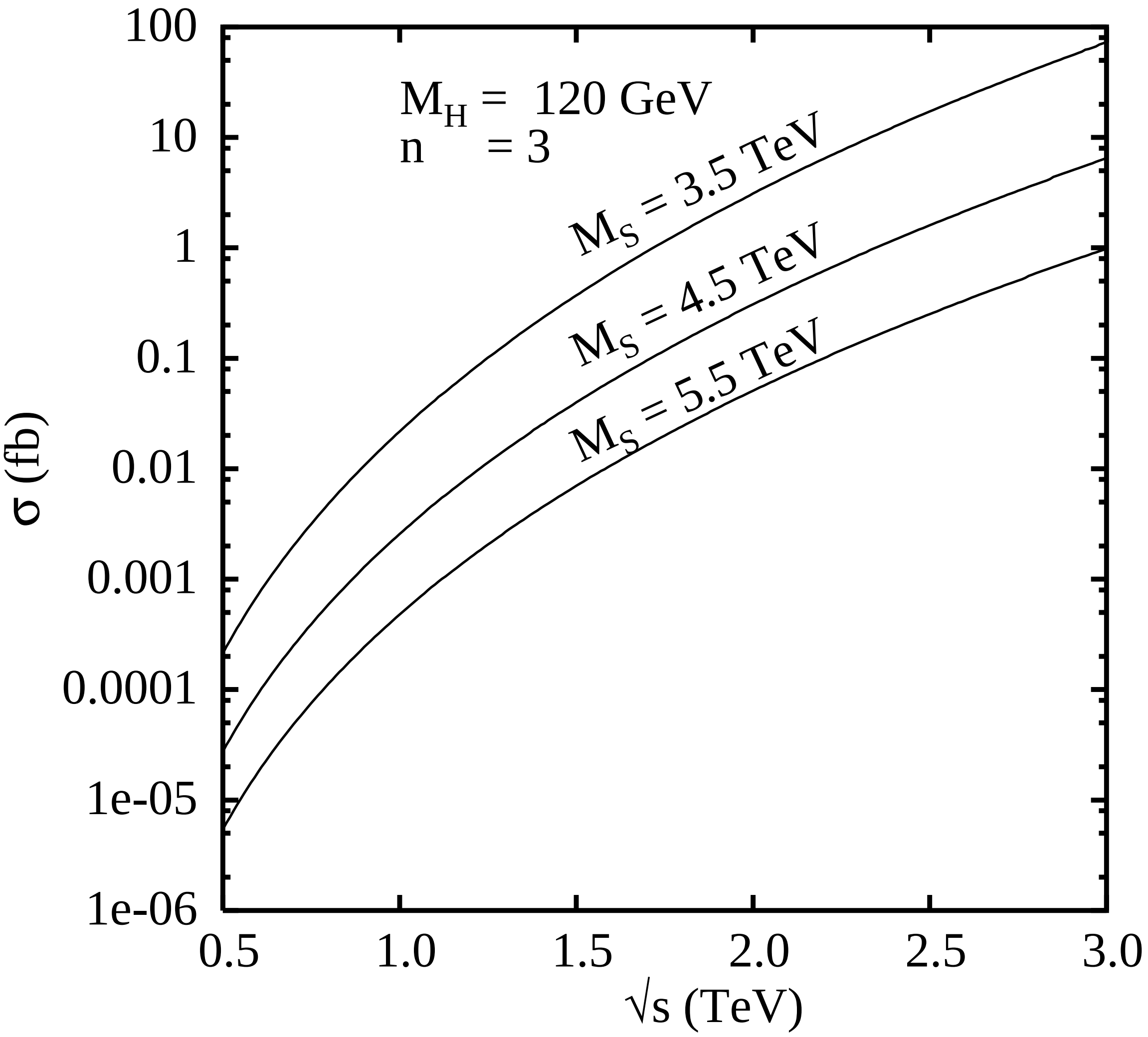

Figure 3: Variation of the cross-section (fb) for $HH\gamma$ production with machine energy in the ADD model with $M_S = 3.5, 4.5$ and 5.5 TeV and $n = 3$. The Higgs mass is set to 120 GeV.