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

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[Work done in collaboration with
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Outlines

1. *Introduction*

2. HHZ *production,*

3. $HH\gamma$ *production,*

4. *Summary*

Introduction

- The gauge hierarchy problem of SM can be solved by extra dimensions.

[N. Arkhani-Hamed *et al.* Phys. Lett. **B429**,263 (1998); Phys. Rev. D **59**, 086004 (1999); I. Antoniadis *et al.* Phys. Lett. **B436**,257 (1998)]

- Our space-time has $D = 4 + n$ dimensions.

- SM particles lives on 4-dimensions, gravity propagates in the extra-dimensions.

- The effective Planck scale (M_{Pl}) can be related to the *fundamental scale* (M_S) by :

$$M_{Pl}^2 \sim R^n M_S^{n+2} \tag{1}$$

- $n \geq 2$, $R \leq 1$ mm, $M_S \sim 1$ TeV

• At TeV scale the gravitational interactions are strong enough to be testable at present and future colliders.

• $e^+e^- \to HHZ$, and $e^+e^- \to HH\gamma$ (which is absent in tree-level SM). in ADD model
[N.G. Deshpande and D.K. Ghosh, hep-ph/0301272]

• In SM $e^+e^- \to HHZ$, to determine λ_{HHH}
[A. Djouadi *et al.*, Eur. Phys. J. **C10**, 27 (1999); C. Castanier *et al.*, hep-ex/0101028]

• In SM $e^+e^- \to HH$: one loop process.

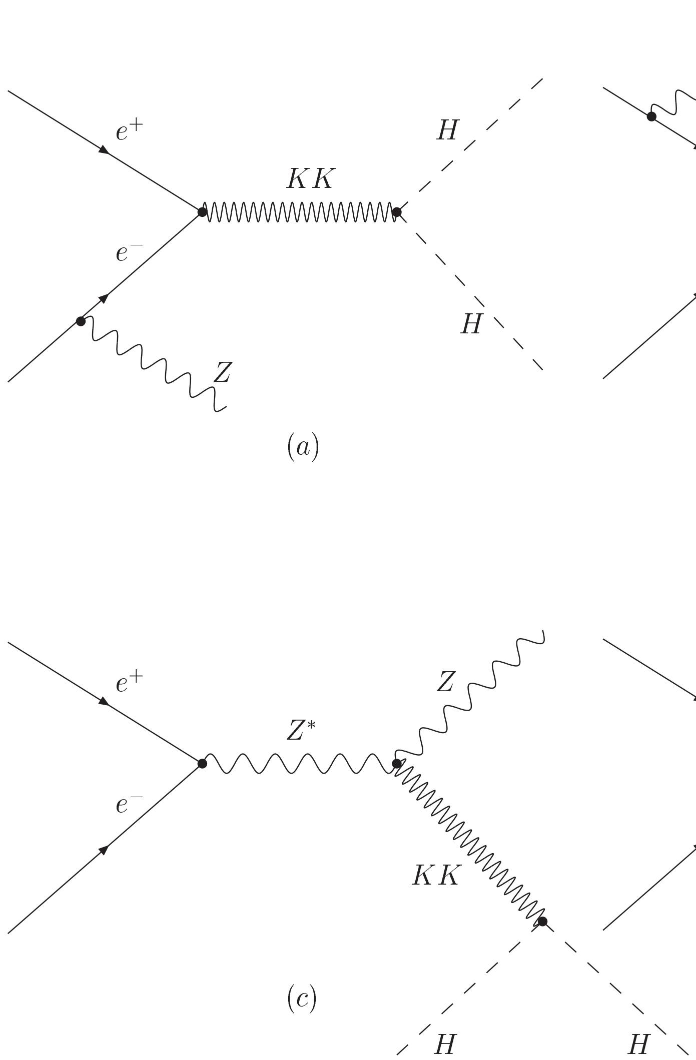
• In ADD model, $e^+e^- \to HH$ process has been studied.
[T. G. Rizzo, Phys. Rev. D**64**, 075002 (2001)]

- In ADD model, $e^{+}e^{-} \rightarrow HHZ$ process receives additional contributions from virtual exchange of both spin-2 and spin-0 KK gravitons.

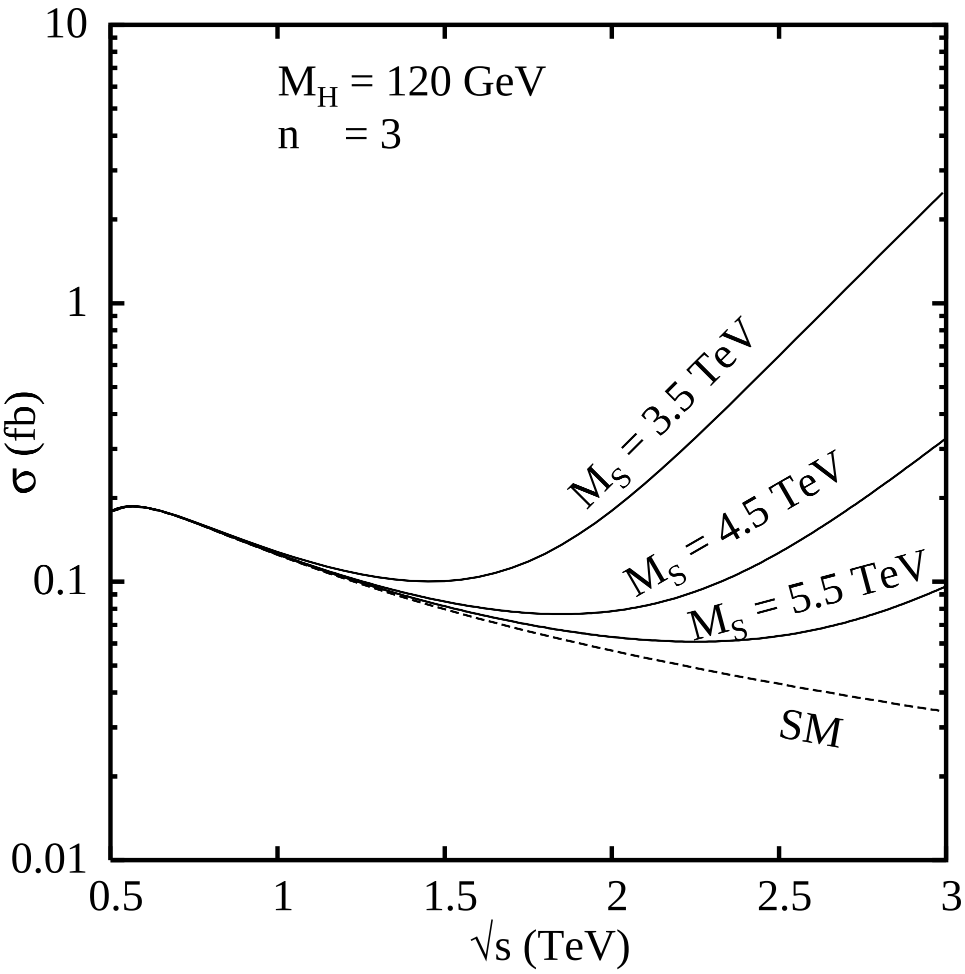
- $\mathcal{M}_{total} = \mathcal{M}_{SM} + \mathcal{M}_{ADD}$

- $\mathcal{M}_{total} = f\left(M_H, \sqrt{s}, M_S, n\right)$

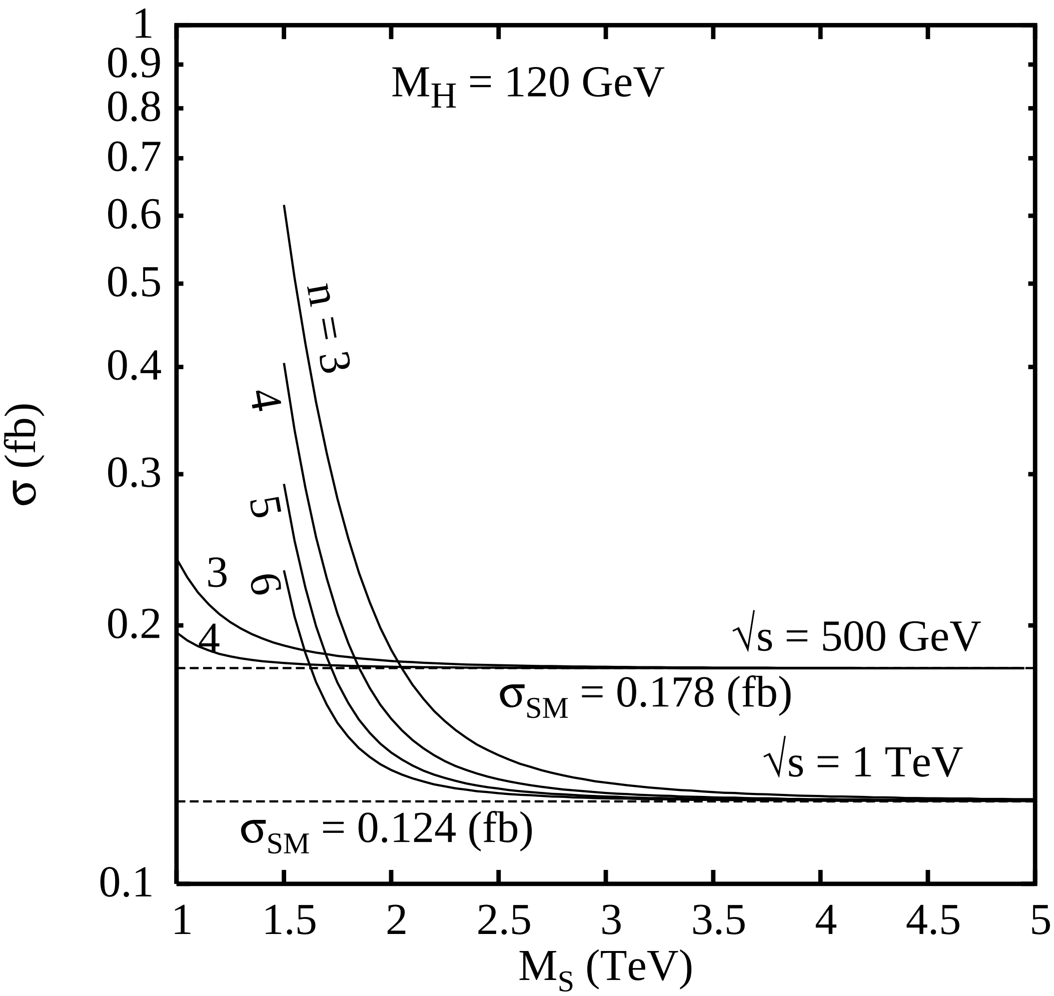
- We fix $M_H = 120$ GeV, and consider $\sqrt{s} = 0.5$ TeV, 1 TeV and 3 TeV.



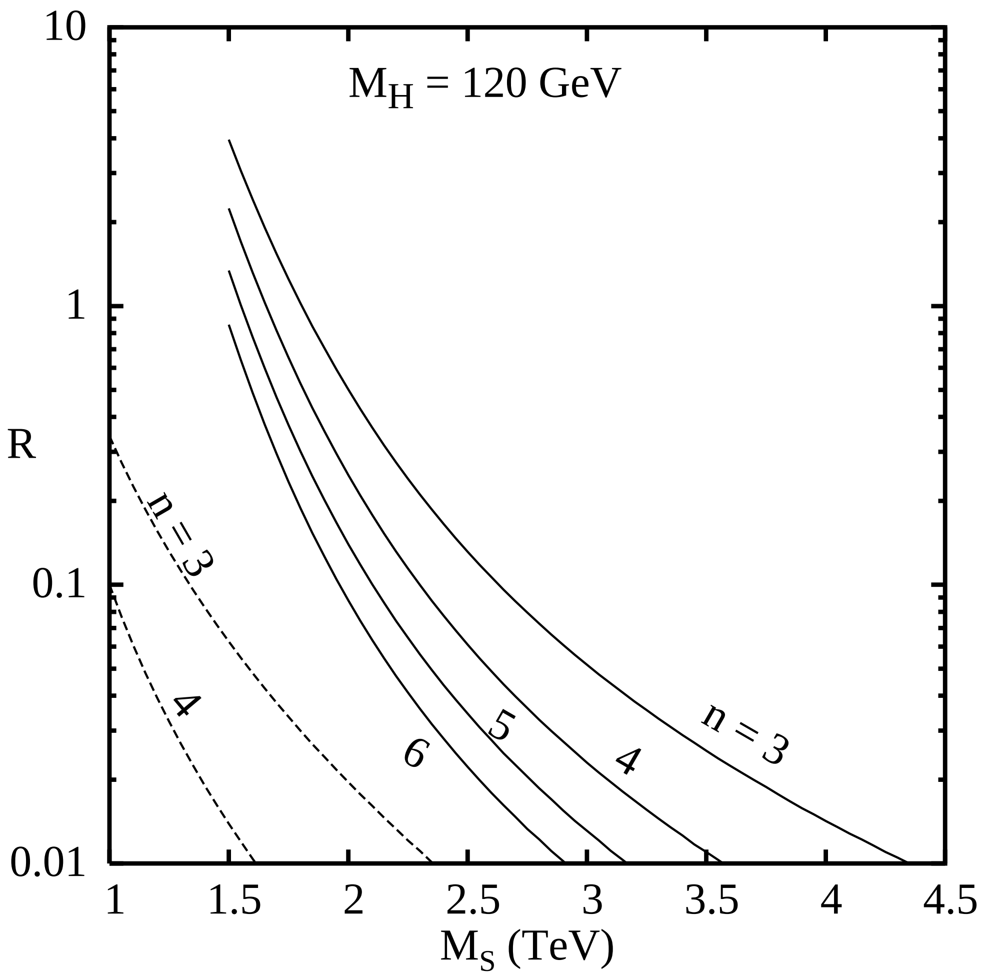
• Feynman diagrams of virtual gravitons (both spin-0 and spin-2) contribution to the process $e^+e^- \to HHZ$.



• Variation of $\sigma(HHZ)$ (fb) 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.



- Variation of $\sigma(HHZ)$ with M_S for $\sqrt{s} = 0.5$ and 1 TeV are shown by the solid lines. The values of extra dimensions (n) are given along the each solid curves. σ_{SM} is shown by the dashed line.



• The fractional deviation $R(\equiv \frac{|\sigma(ADD)-\sigma(SM)|}{\sigma(SM)})$ of the cross-section for 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.

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

• 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.

• This limit is obtained by considering the 10% error on the HHZ cross-section measurement at $\sqrt{s} = 500$ GeV with $\mathcal{L} = 2$ ab^{-1} as claimed in hep-ex/0101028.

- In ADD model, we also study $e^+e^- \to HH\gamma$.

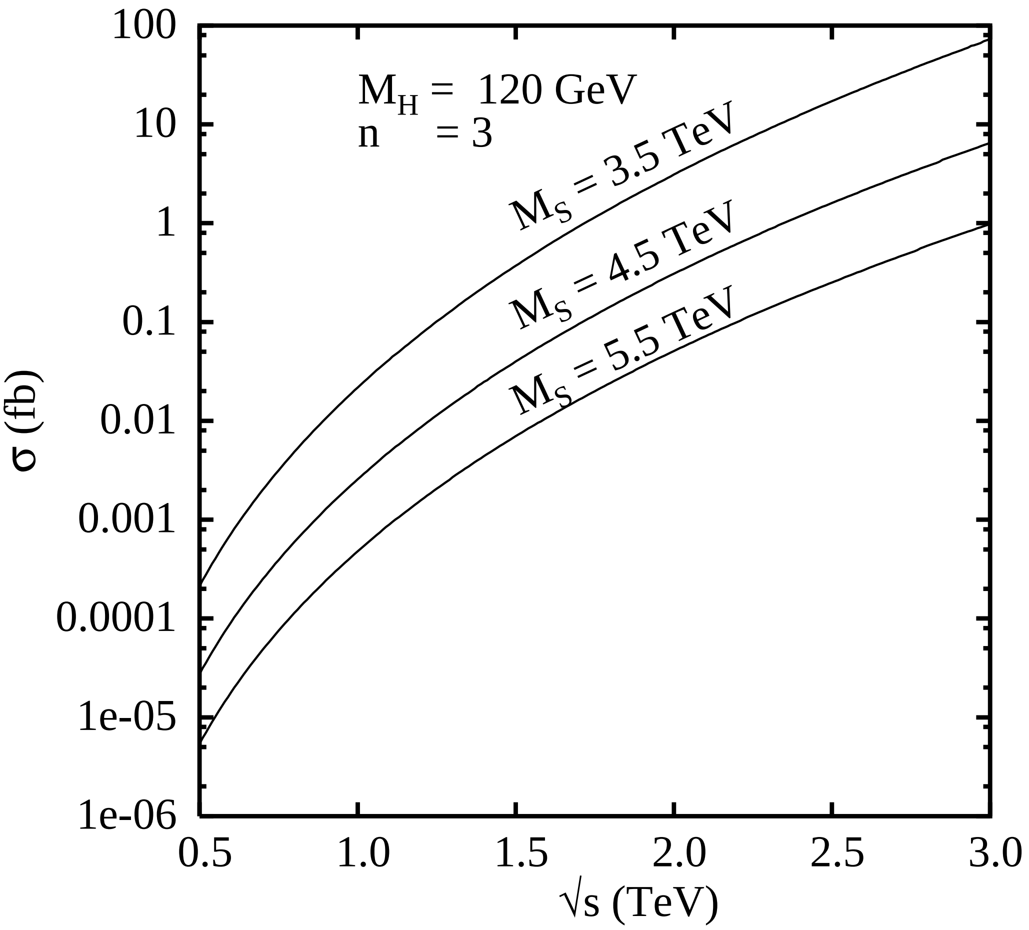
$$E_\gamma > 10 \text{ GeV}, \quad (2)$$
$$|\cos\theta_\gamma| < 0.98 \quad (3)$$

- In SM model, $e^+e^- \to HH\gamma$ can occur at higher order.

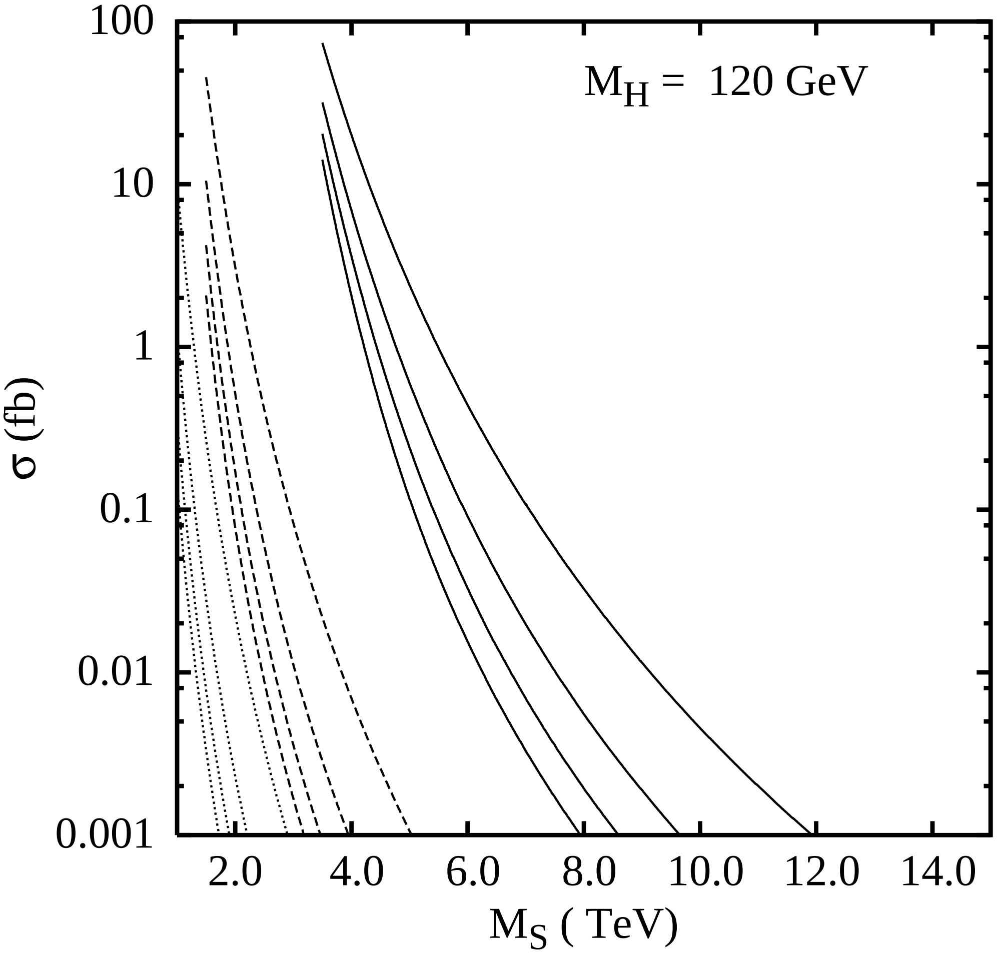
- The main possible background : $e^+e^- \to HZ\gamma$, with $Z \to b\bar{b}$ looking like a Higgs decay.

- Using CompHEP, we have computed $\sigma^B_{eff} = \sigma(e^+e^- \to HZ\gamma) \times Br(Z \to b\bar{b}) \times Br(H \to b\bar{b})$

- $\sigma^B_{eff} =$ 0.50 (fb), 0.15 (fb), 0.023 (fb) for $\sqrt{s} =$ 0.5 TeV, 1 TeV and 3 TeV respectively.



• Variation of the $\sigma(HH\gamma)$ with $\sqrt{s}$ in the ADD model. $M_S = 3.5, 4.5$ and 5.5 TeV and $n = 3$.



• Variation of the $\sigma(HH\gamma)$ with M_S in the ADD model. The solid, dashed and dotted curves with $n = 3-6$ from right to left correspond to $\sqrt{s} = 3$ TeV, 1 TeV and 0.5 TeV respectively.

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

• 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.

Summary

- We have studied the implications of KK graviton contribution to HHZ and $HH\gamma$ production at e^+e^- collider.

- The spin-2 and spin-0 mode of KK gravitons contribute to these processes substantially.

- The existence of KK gravitons may be discovered through more direct channels.

- We have obtained 5σ discovery limit on M_S using these two modes.

- The bounds obtained here are only suggestive and may change when one take into account proper detector simulation and complete background estimations.