Interference effects due to Kaluza-Klein towers in collider processes

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Workshop on Multi-Higgs Models
Lisboa, Portiugal, September, 3rd, 2014

Outline

- **Introduction**

  - *brane world models as possible extensions of the Standard Model (SM)*

- **W', Z', γ' coming from Extra Dimensions**

  - *interference effects*

(E. Boos, V. Bunichev, M. Perfilov, M. Smolyakov, I. Volobuev:

«The specificity of searches for W', Z' and γ' coming from extra dimensions»

JHEP 06 (2014) 160 ,

E. Boos, M. Perfilov, M. Smolyakov, I. Volobuev:

«Searches for W' and Z' in models with large extra dimensions»

Theor.Math.Phys.170: 90-96, 2012

- **Higgs-radion interference in collider processes**

  - *possible significant effects*

Models with Universal Extra Dimensions (UED)

- Many BSM theories predict the existence of massive charged and neutral vector particles (in addition to the gauge bosons of the SM)

  - extension of the SM gauge group

  - excitations of the SM gauge bosons

  (lowest excitations of W,Z, γ are usually called W',Z' and γ')

- Determination of the BSM theory to which new bosons correspond

  - if the additional bosons are found

- Study of the specific features of the excitations of the SM gauge bosons in models with Universal Extra Dimensions (UED)

Models with Universal Extra Dimensions (UED)

- Brane-world models as possible extensions of the SM
- Certain fields of the SM and the gravity propagate either in the flat bulk or in the Randall-Sundrum bulk
- RS setup with stabilizing scalar field provides an example

  of a concrete realization of a stabilized brane-world model

  - the size of the extra space dimension should be stabilized in order to get a physically meaningful picture
- We consider the scenario where only SM gauge fields live in the bulk of a stabilized brane-world model

  - lighter KK excitations of the SM fields may be allowed

W-boson and its KK-tower

- Effective Lagrangian of the W boson KK tower:

$$L_{eff\_W\_KK} = \frac{g_1}{\sqrt{2}}(J^{+\mu}W'^{-}_{\mu} + J^{-\mu}W'^{+}_{\mu}) - \frac{g_1^2}{2M^2_{W'\_\mathrm{sum}}}J^{+\mu}J^{-}_{\mu}$$

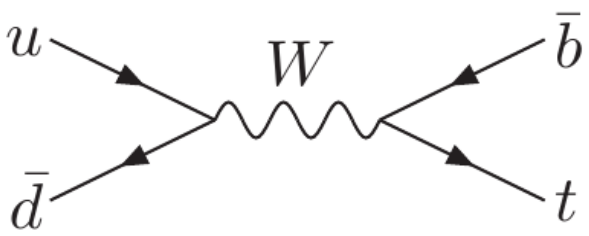
g_1 – coupling constant of W' to the weak charged current $J^{+\mu}$

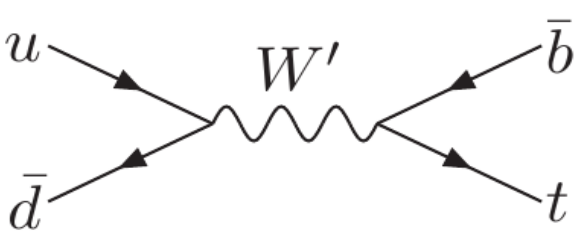
$M_{W'_{sum}}$ is the mass parameter taking into account the contribution of the KK tower above W'
(effective mass is just a little larger than that of W')

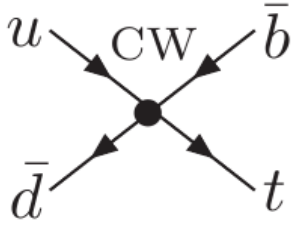
- Effective Lagrangian for the towers of γ and Z have the same form with the weak charged current replaced by the electromagnetic current and the weak neutral current respectively
- Values for excitation masses have been chosen *in the energy range* of LHC (but not yet excluded) and *close to the Snowmass 2013*
- We take into account first KK mode + all other modes (CW)

W-boson and its KK-tower

- Single top quark production and $\mathbf{p,p} \rightarrow \nu_\mu \mu^+$ processes at the LHC
- Representative set of diagrams for single top:







the contact term

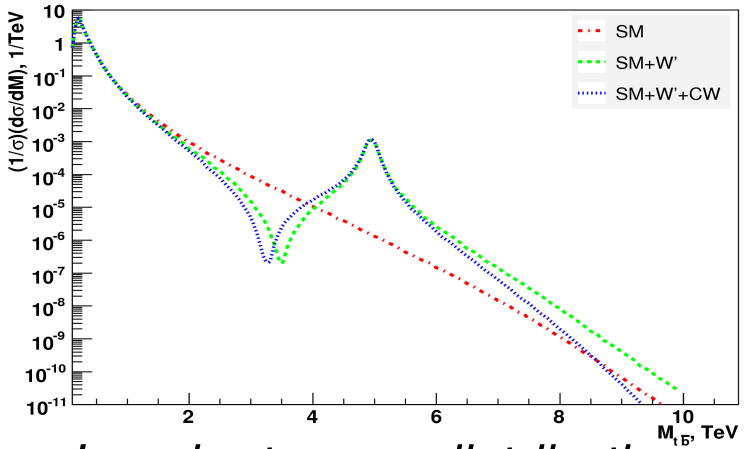
- Amplitude corresponding to diagrams:

$$\frac{g^2}{2}(\bar{d}\gamma_\mu(1-\gamma_5)u)(\bar{t}\gamma^\mu(1-\gamma_5)b)\left(\frac{1}{p^2-M_W^2}+\frac{1}{p^2-M_{W'}^2}-\frac{1}{M_{W'\_sum}^2}\right)$$

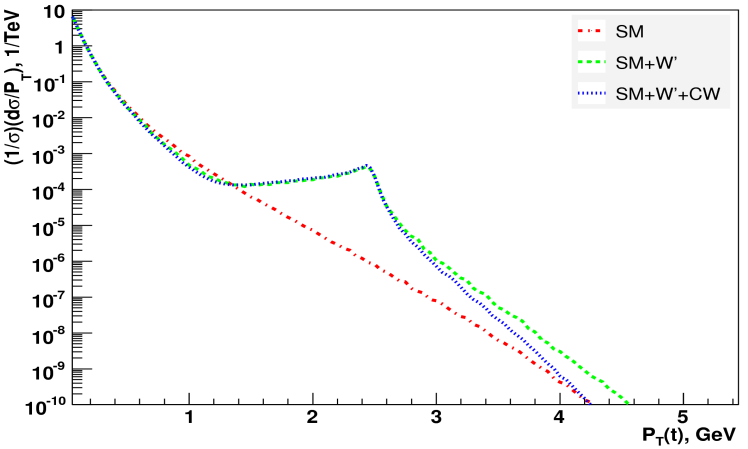
takes into account the contribution of the sum of the one-boson-exchange diagrams with all the modes above the W'

- This structure of the amplitude manifests the origin of the **interference** between the contributions of different diagrams

W-boson and its KK-tower

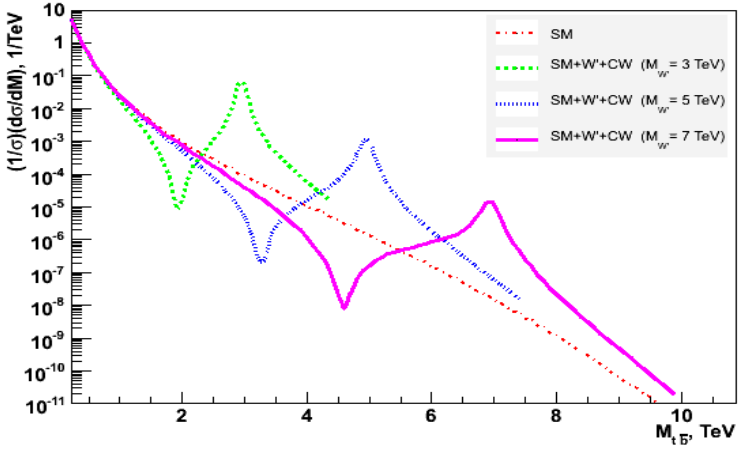


Invariant mass distribution

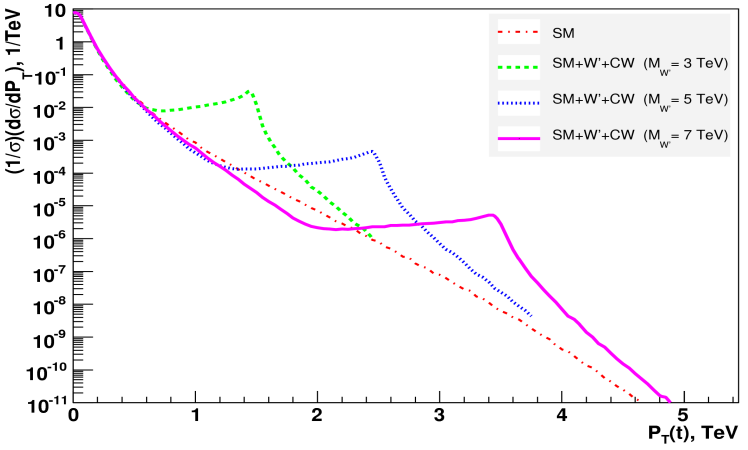


p_T distribution

for the single top production for 14 TeV (LHC) for M(W') = 5 TeV with and without the contribution of the W' KK tower



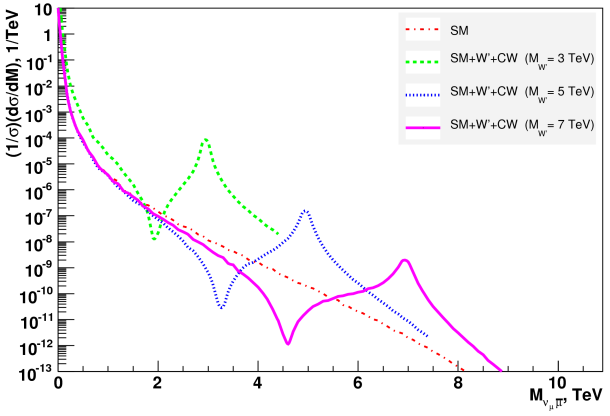
Invariant mass distribution

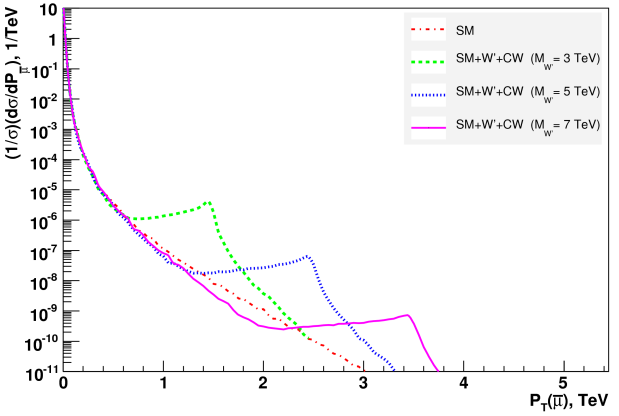


p_T distribution

for the single top production for 14 TeV (LHC) for three different values of M(W') masses (3, 5 and 7 TeV) with and without the contribution of the W' KK tower

W-boson and its KK-tower





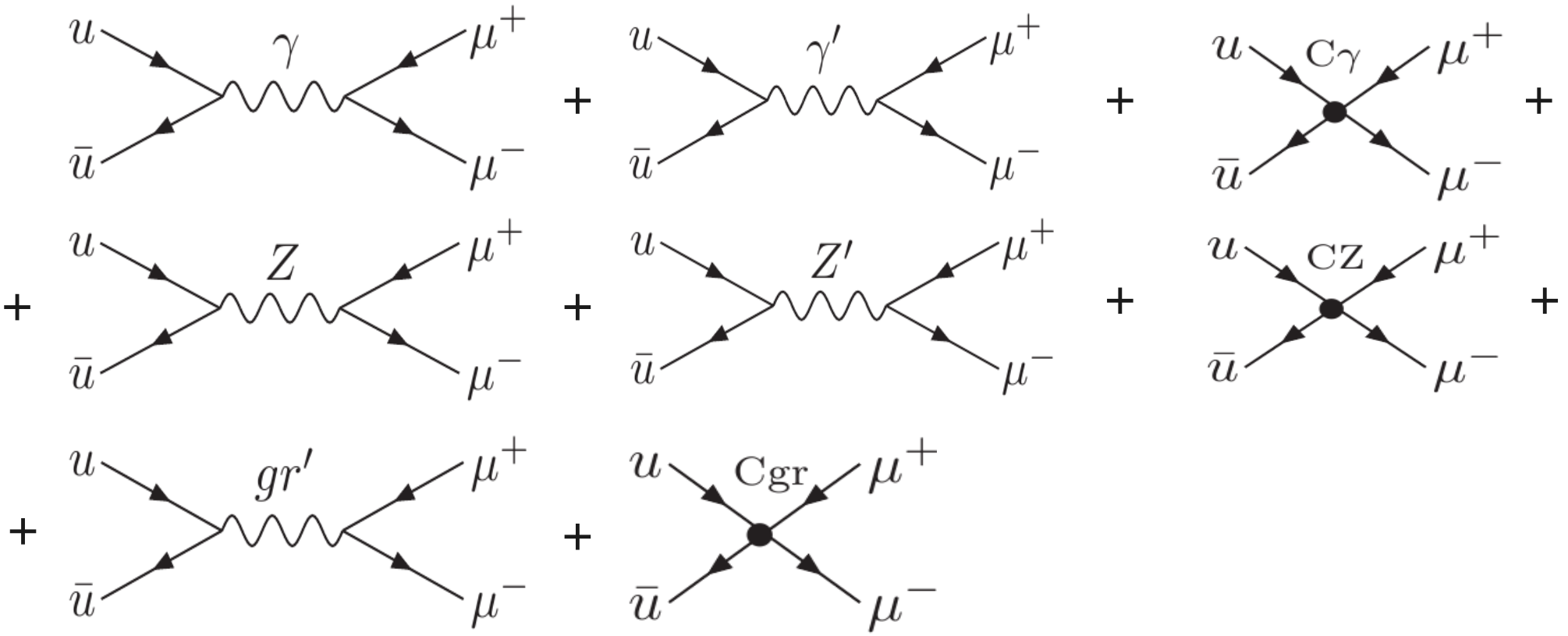
Invariant mass distribution *p_T distribution*

of the $\mathbf{p,p} \rightarrow \nu_\mu \mu^+$ *process for 14 TeV (LHC) for three different values of M(W') masses (3, 5 and 7 TeV) with and without the contribution of the W' KK tower*

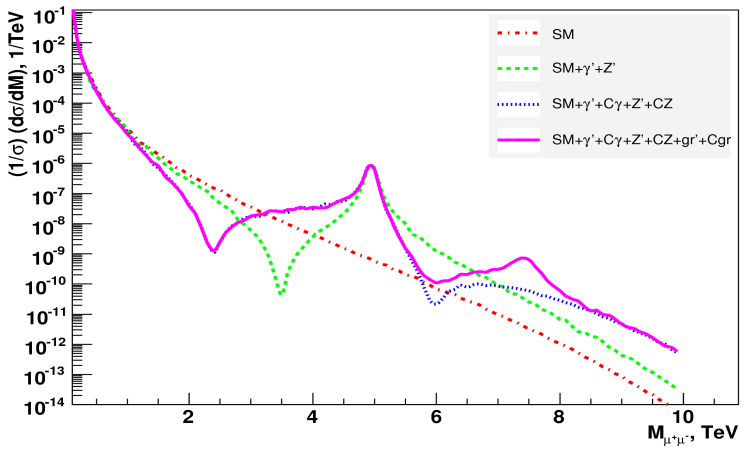
- interference with the contribution of the rest of the KK tower changes the curves significantly
- interference effects are, in principle, observable for the W' boson mass as large as 7 TeV

Z, γ and KK-towers

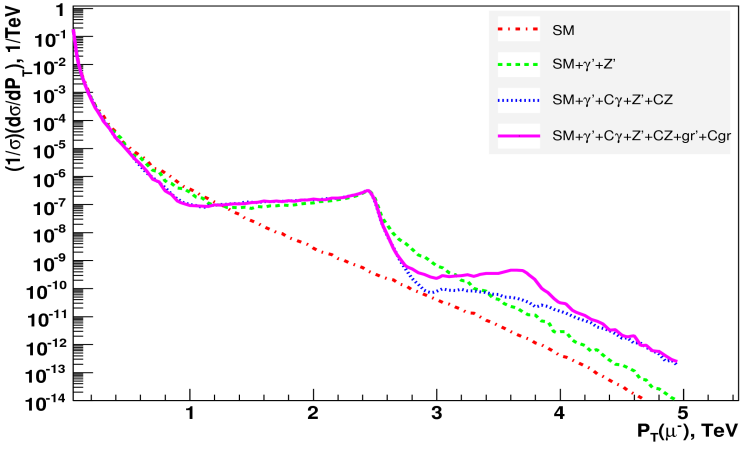
- Drell-Yan processes $\mathbf{p}, \mathbf{p} \rightarrow \mu^+ \mu^-$ at the LHC
- The contribution of the KK graviton gr' and its tower is also taken into account



Z, γ and KK-towers

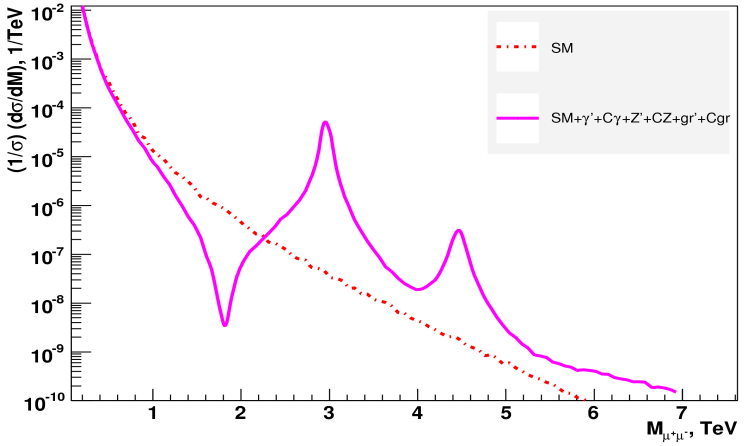


Invariant mass distribution

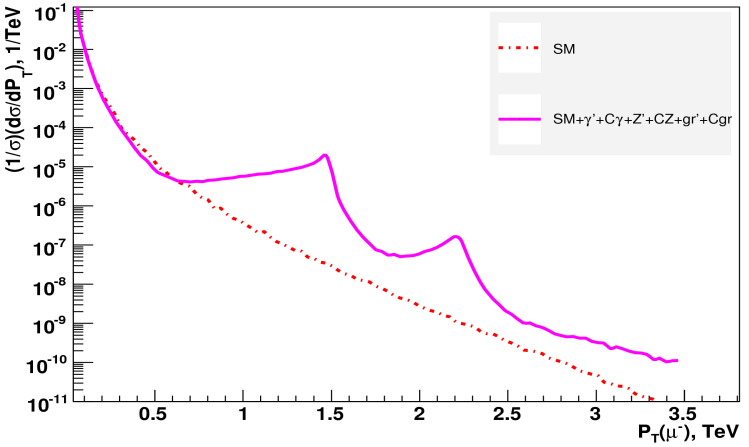


p_T distribution

for the Drell-Yan process for 14 TeV (LHC) for $\mathbf{M_{\gamma'}=M_{Z'}=5\,TeV\,,M_{gr'}=7.5\,TeV}$



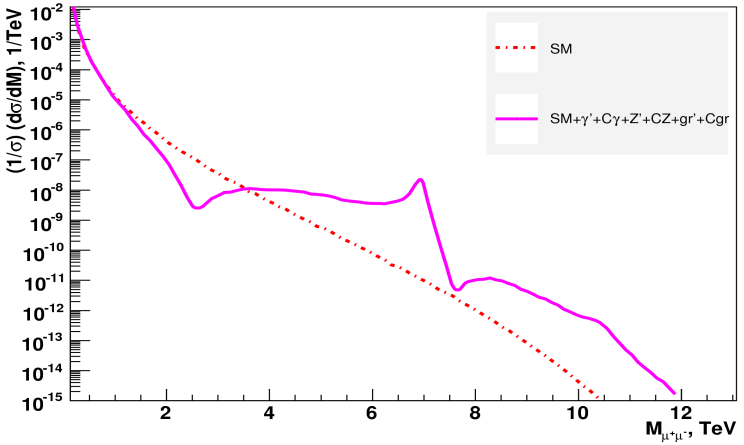
Invariant mass distribution

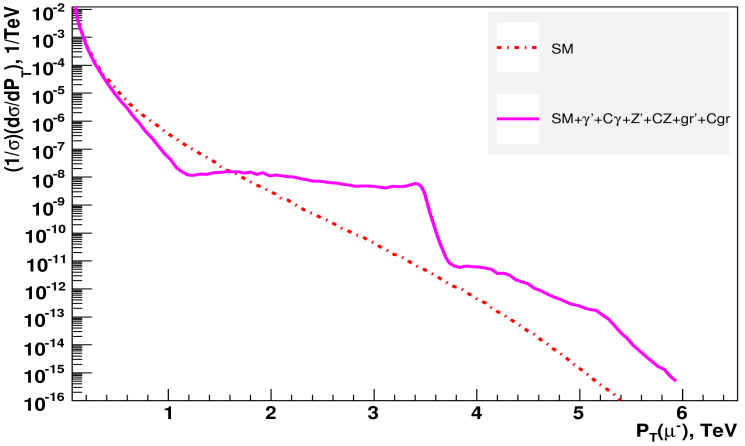


p_T distribution

for the Drell-Yan process for 14 TeV (LHC) for $\mathbf{M_{\gamma'}=M_{Z'}=3\,TeV\,,M_{gr'}=4.5\,TeV}$

Z, γ and KK-towers





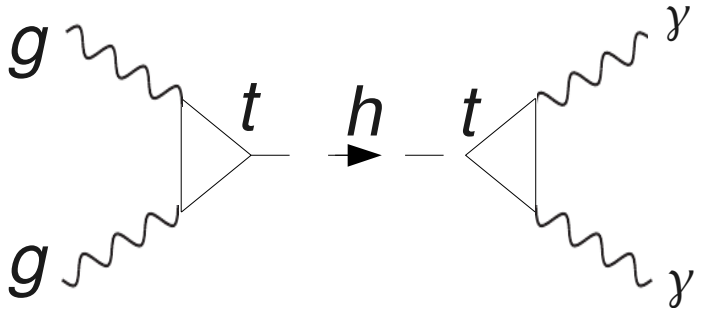
Invariant mass distribution *p_T distribution*

for the Drell-Yan process for 14 TeV (LHC) for $\mathbf{M_{\gamma'}=M_{Z'}=7\,TeV\,,M_{gr'}=10.5\,TeV}$

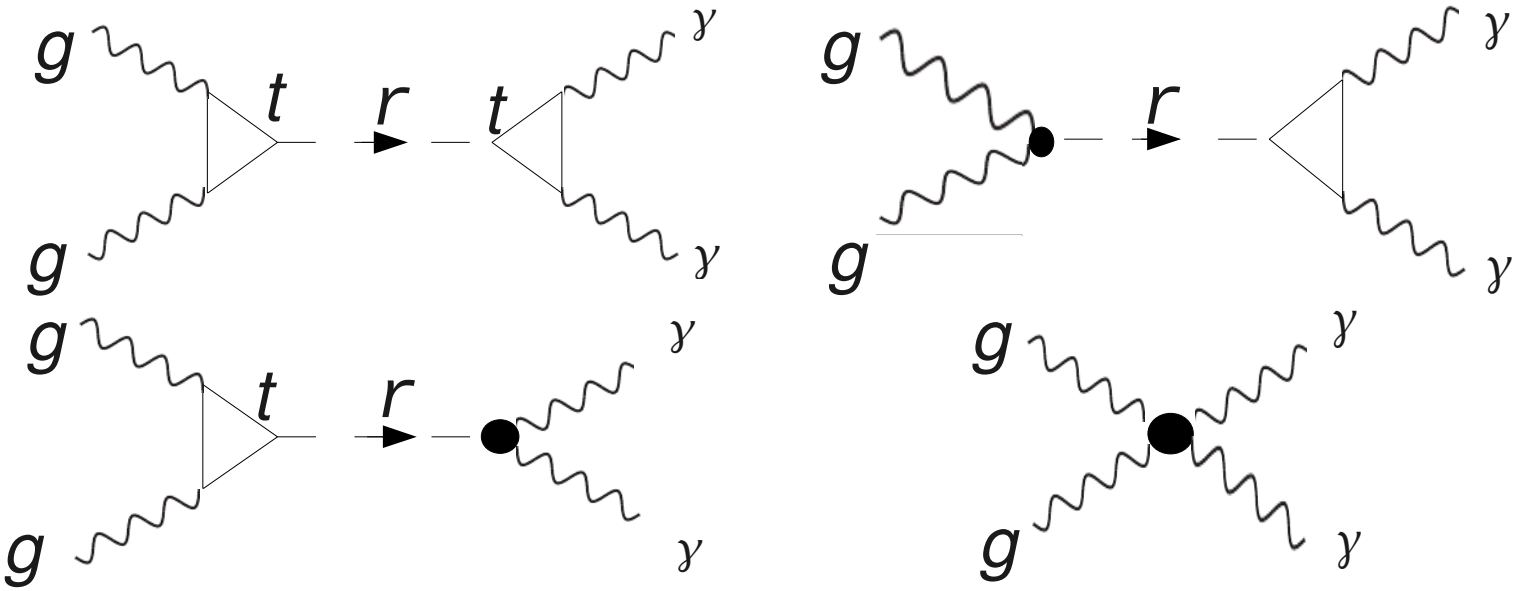
- interference with the contact interaction terms is quite definite and is very similar to that in single top production
- the absence of an interference between the first graviton KK excitation and that of the Z boson

Higgs-radion interference

- Higgs production at LHC:



- RS setup provides an example of concrete realization of a stabilized brane world model and lowest scalar state (**radion**) might be lighter than all other KK escitations



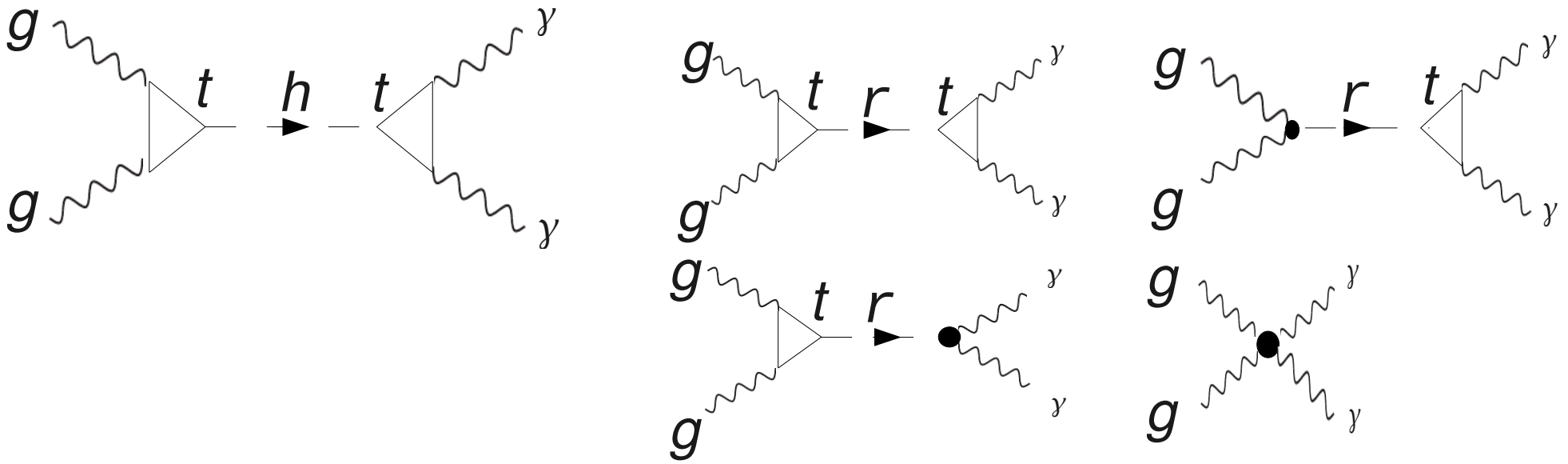
- Usually the masses of SM Higgs boson and radion are considered ***to be close***

  - Higgs-radion mixing

(Nucl.Phys. B595 (2001) 250-276, Phys.Rev.D63:065002,2001)

Higgs-radion interference

- If the mass of the radion is larger than that of the SM Higgs (400-500 GeV) the *radion and its KK tower look as if they were an effective KK tower of the Higgs boson and one can predict interference effects similar to the ones that have been described above*



- The interference can give a significant contribution

Conclusions

- The qualitative description of the interference phenomena between SM gauge bosons and their lower Kaluza-Klein excitations has been performed for LHC energy
- Modification of the distribution tails is characteristic for the processes mediated by particles from ED
- An observation of such interference effects for W', Z' and γ' and the presence of the first tensor KK graviton can be interpreted as a strong argument in favor of the existence of extra dimensions
- We expect similar interference effects between SM Higgs boson and the scalar fields of the stabilized brane-world model (radion) (ongoing research)