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Top Quarks Spin Correlations with Graviton in ADD and RS Models at the Large Hadron Collider

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In LHC physics we study the spin correlation of top-antitop pairs production to investigate the production mechanism of heavy quarks[1]. The s-channel process mediated by graviton Kaluza-Klein modes in ADD model with several extra dimensions[2] or in the Randall-Sundrum model with only one extra dimension[3] contribute to the top-antitop pair production and affects the resulting top spin correlations. We calculated the full density matrix for the top-antitop pair production. We find a sizable deviation of the top spin correlations from the Standard.

1. Spin correlation

At hadron collider, the top-antitop quark pair is produced through the processes of quark-antiquark pair annihilation and gluon fusion:

$$i \to t + \bar{t}, \;\; i = q\bar{q}\,, gg\,. \qquad (1)$$

The former is the dominant process at the Tevatron, while the latter is dominant at the LHC. The best way to analyze the top-antitop spin correlations is to see the angular correlations of two charged leptons produced by the top-antitop quark leptonic decays. The coefficient $\mathcal{A}$ denotes the spin asymmetry between the produced top-antitop pairs with like and unlike spin pairs:

$$\mathcal{A} = \frac{\sigma(t_\uparrow\bar{t}_\uparrow) + \sigma(t_\downarrow\bar{t}_\downarrow) - \sigma(t_\uparrow\bar{t}_\downarrow) - \sigma(t_\downarrow\bar{t}_\uparrow)}{\sigma(t_\uparrow\bar{t}_\uparrow) + \sigma(t_\downarrow\bar{t}_\downarrow) + \sigma(t_\uparrow\bar{t}_\downarrow) + \sigma(t_\downarrow\bar{t}_\uparrow))} \qquad (2)$$

It could be obtained from the following double distribution [1]

$$\frac{1}{\sigma}\frac{d^2\sigma}{d\cos\theta_{l^+} d\cos\theta_{l^-}} = \frac{1 - \mathcal{A}\kappa_{l^+}\kappa_{l^-}\cos\theta_{l^+}\cos\theta_{l^-}}{4} \qquad (3)$$

with $\kappa_{l^+} = \kappa_{l^-} = 1$ for leptons. Here σ denotes the cross section for the process of the leptonic decay modes, and $\theta_{l^+}(\theta_{l^-})$ denotes the angle between the top (antitop) spin axis and the direction of motion of the antilepton (lepton) in the top (antitop) rest frame. In the SM, at the lowest order of α_s, the spin asymmetry is $\mathcal{A} = +0.302$ for the LHC.

The spin-2, nature of the intermediate KK gravitons, can give rise to characteristic spin configurations and angular distributions for outgoing particles,

2. ADD scenario[4]

The results for the spin asymmetry $\mathcal{A}$ in ADD model calculate from density matrix[4] are presented in Fig. 1 as a function of the scale M_D for the $q\bar{q} \to t\bar{t}$ and the $gg \to t\bar{t}$ channels. We can see sizable deviations from the SM at the scale below ~ 2 TeV. Note that for the $q\bar{q} \to t\bar{t}$ channel the cross section is independent of the sign of λ (coefficient for addition (+1) or substraction (-1) of graviton amplitude to SM).

The total spin asymmetries is dominated by the gluon fusion since the gluon fusion is the domi-

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nant process for the top-antitop quark pair production at the LHC.

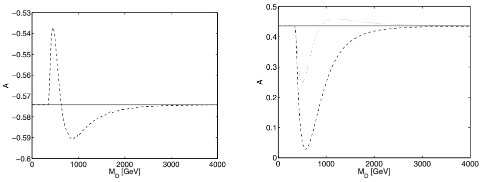

Figure 1. Spin asymmetry $\mathcal{A}$ for the $q\bar{q} \to t\bar{t}$ channel (a) and the $gg \to t\bar{t}$ channel (b) as a function of the scale M_D at the LHC with $E_{CMS} = 14$ TeV.

3. RS scenario[5]

Invariant amplitude for top-antitop production is finite in the RS scenario[3], since the RS model is 5-dimensional, while it diverges in the ADD scenario. There may be a graviton resonance in with mass $m_1 \geq 600$ GeV. In the SM top pair production, resonance is expected in the process $gg \to H \to t\bar{t}$. Virtual graviton mediating process the SM process at the rest frame of graviton and Higgs, respectively, create possibilities to observe new physics at resonance pole Fig. 2.

Interaction between gravitons and the SM fields are effectively given by $\Lambda_\pi = e^{\kappa r_c \pi} \bar{M}_{pl}$ ($\bar{M}_{pl}$ is reduced Planck mass) is an effective coupling between the massive graviton and the SM fields. General expression of the invariant amplitudes in momentum space is obtained as **(actually this amplitude can be obtained by just replacing** $4\pi\lambda/M_D^4$ **with** $-\frac{1}{\Lambda_\pi^2}\sum_{n=1}^{\infty}\frac{1}{s-m_n^2-im_n\Gamma_n}$

4. Conclusion

In bouts scenarios ADD, RS of graviton we have found sizeable deviations from the SM of the spin asymmetry in the production of top-antitop pairs.

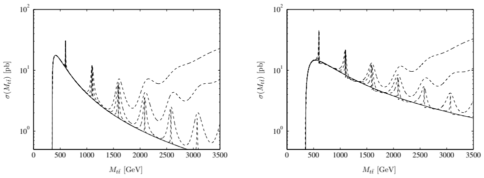

Figure 2. The cross section of the top-antitop quark pair production by quark-antiquark pair annihilation (left) and by gluon fusion (right) on the center-of-mass energy of colliding partons[5].

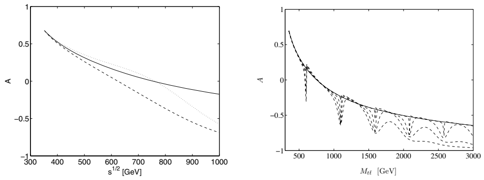

Figure 3. Spin asymmetries $\mathcal{A}$ as function of the top-antitop invariant mass $M_{t\bar{t}}$. The solid lines correspond to the SM. The dashed lines correspond to the ADD model ($M_D = 1TeV$) (left) and to the RS model ($\kappa/\bar{M}_{\rm pl}$=0.01, 0.04, 0.07, 0.1) (right).

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