Top Spin Correlations in Theory with Large Extra-Dimensions at Large Hadron Collider

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Abstract

We examine the top spin correlation in 4-dimensional effective theory of ADD scenario.

Introduction

Large Extra Dimensions

- Arkani-Hamed, Dimopoulos and Dvali (ADD) proposed a solution of gauge hierarchy problem in theories with compactified extra dimensions with large radii (large extra dimensions).
- The Planck scale M_{pl} is written by fundamental scale M_D and compactification radius R: $M_{pl} = M_D(M_D R)^{n/2}$ $(M_D \sim \mathcal{O}(\text{TeV}))$.
- In this scenario, it is assumed that our world is confined on (3+1)-dimensional manifold called brane embedded in higher dimensional space-time.
- Graviton only can propagate into the whole space-time.
- Strength of gravitational interaction is enhanced from $1/M_{pl}$ to $1/M_D$ through a large number of Kalzua-Klein excitations in 4-dimensional effective theory valid below M_D.
- This leads to new phenomena predicted for collisions at high energies.
- In virtual graviton exchange process, since graviton has spin 2, it gives rise to characteristic spin configuration for outgoing states.

Top Spin Correlation

- Top quark pair production is a good candidate to study the spin configuration.
- The top quark has exceptionally high mass and a short life-time 10^{-24} s.
- During this short time the top quark cannot hadronise and decays as a free quark.
- Therefore, the decay products maintain the spin information of the quark.
- The decay products of top quark pair have a significant angular correlation between them.

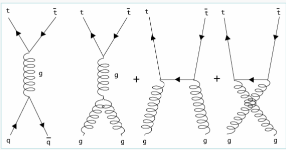
Purpose of our work

- We examine the effect of extra-dimensions on spin correlation of top-antitop pair and angular distribution of the decay products at LHC in theory with large extra dimensions (ADD scenario).

What is the Top Spin Correlation ?

Top-antitop quark pair production in pp collision at LHC in the SM

$$g + g \to t + \bar{t} \quad (87\%) \qquad \sqrt{s} = 14\,\text{TeV} \qquad (1)$$
$$q + \bar{q} \to t + \bar{t} \quad (13\%)$$



Decay of top quark

$$t \to bW^+ \to b\bar{l}\nu_{\bar{l}}, \quad bu\bar{d}, \cdots$$

- We focus on leptonic decay channels since it is the most efficient spin analyzer.

Double spin correlation

$$\frac{1}{\sigma_{tot}} \frac{d^2\sigma_{tot}}{d\cos\theta_l \, d\cos\theta_{\bar{l}}} = \frac{1 + \mathcal{A}\cos\theta_l \cos\theta_{\bar{l}}}{4}$$

- σ_{tot} : total cross section of $pp \to t\bar{t} \to b\bar{l}\nu_l \bar{b} l \bar{\nu}_l$ at parton level
- $\theta_l(\theta_{\bar{l}})$: angle between a spin of antitop (top) and a direction of lepton (antilepton) momentum
- $\mathcal{A}$: the asymmetry of top-antitop quark production of unlike and like spin pairs

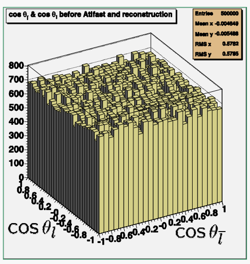
$$\mathcal{A} = \frac{\sigma(t_\uparrow \bar{t}_\downarrow) + \sigma(t_\downarrow \bar{t}_\uparrow) - \sigma(t_\uparrow \bar{t}_\uparrow) - \sigma(t_\downarrow \bar{t}_\downarrow)}{\sigma(t_\uparrow \bar{t}_\uparrow) + \sigma(t_\downarrow \bar{t}_\downarrow) + \sigma(t_\uparrow \bar{t}_\downarrow) +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

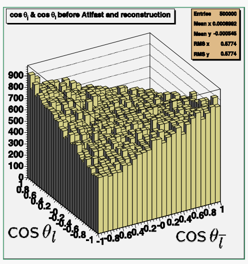
- $\sigma(t_\alpha \bar{t}_\beta)$: the cross section of top-antitop pair production by Eq. (1) with polarized spin state at parton level

Angular correlation comes from the asymmetry $\mathcal{A}$.

Number of $t\bar{t}$ events for $\cos\theta_l$ and $\cos\theta_{\bar{l}}$

- No spin correlation $\mathcal{A} = 0$
- Standard Model $\mathcal{A} = -0.31$



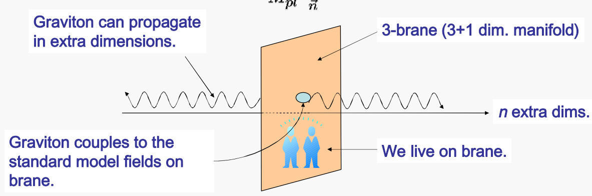


Large Extra Dimensions (model setup)

Setup

- 3-brane is embedded in the bulk (n compactified extra-dimensions)
- The standard model fields reside only on the brane.
- Graviton can propagate into the whole space-time.
- Graviton interacts with the standard model fields only on the brane.

$$\mathcal{L}_{int} = -\frac{1}{\bar{M}_{pl}} \sum_{\vec{n}} G^{(\vec{n})}_{\mu\nu} T^{\mu\nu}$$

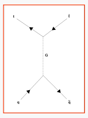


- Enhancement of strength of gravitational interaction is realized after summing up infinite tower of Kaluza-Klein graviton excitations.

Spin Correlation in ADD scenario

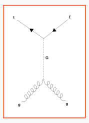
Squared amplitude

- New contributions to Eq. (1) : Virtual graviton exchange.



Total squared amplitude for initial $q\bar{q}$ state

$$|\mathcal{M}(q\bar{q} \to t_\uparrow \bar{t}_\uparrow \text{ or } t_\downarrow \bar{t}_\downarrow)|^2 = \frac{g^4}{9}(1-\beta^2)\sin^2\theta + \frac{f_G s^4 \beta^2}{2}(1-\beta^2)\sin^2 2\theta,$$
$$|\mathcal{M}(q\bar{q} \to t_\uparrow \bar{t}_\downarrow \text{ or } t_\downarrow \bar{t}_\uparrow)|^2 = \frac{g^4}{9}(1+\cos^2\theta) + \frac{f_G s^4 \beta^2}{2}(\cos^2 2\theta + \cos^2\theta)$$
$$f_G \equiv \pi\lambda/2M_D^4 \qquad \lambda = \pm 1$$



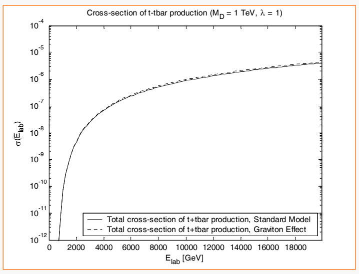
Total squared amplitude for initial gg state

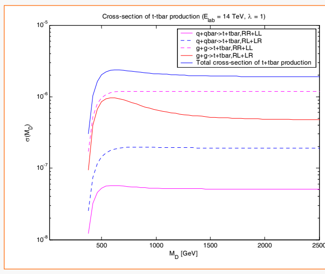
$$|\mathcal{M}(gg \to t_\uparrow \bar{t}_\uparrow \text{ or } t_\downarrow \bar{t}_\downarrow)|^2 = \frac{g^4\beta^2}{96}\mathcal{Y}(\beta,\cos\theta)(1-\beta^2)(1+\beta^2+\beta^2\sin^4\theta) + \mathcal{Z}(\beta,\theta,s) f_G s^2 \beta^2 (1-\beta^2)\sin^4\theta$$
$$|\mathcal{M}(gg \to t_\uparrow \bar{t}_\downarrow \text{ or } t_\downarrow \bar{t}_\uparrow)|^2 = \frac{g^4\beta^2}{96}\mathcal{Y}(\beta,\cos\theta)(1+\cos^2\theta) + \mathcal{Z}(\beta,\theta,s) f_G s^2 \beta^2 \sin^2\theta(1+\cos^2\theta)$$
$$\mathcal{Y}(\beta,\cos\theta) = \frac{7+9\beta^2\cos^2\theta}{(1-\beta^2\cos^2\theta)^2} \qquad \mathcal{Z}(\beta,\theta,s) = \frac{g^2}{4(1-\beta^2\cos^2\theta)} + \frac{3}{4} f_G s^2$$

- These processes contribute to the spin asymmetry $\mathcal{A}$ (Eq. (2)) .

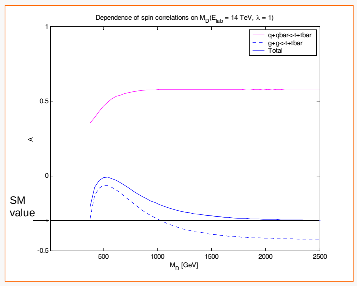
Numerical Result

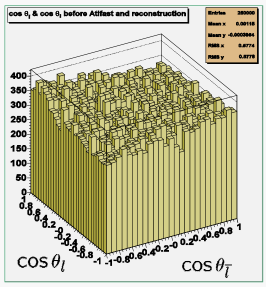
- For our computation we used PDF CTEQ5M1, scale $Q = m_t$ (m_t : top mass), cut $\sqrt{s} < M_D$.
- Plots of total cross section of top-antitop pair production against center of mass energy and fundamental scale M_D.





- Plot of the spin asymmetry against M_D
- Number of events for $\cos\theta_l$ and $\cos\theta_{\bar{l}}$, $\mathcal{A} = -0.09$, $M_D = 1\,\text{TeV}$ $\lambda = 1$





Conclusion

- With the fundamental scale of the extra dimensional theory being lower than around 2.0 TeV we find the sizable deviation of the spin asymmetry from the SM result while the deviation of the cross section of top pair production is small.

⇨ Spin asymmetry is a good probe of new physics

- **Future Plan**
  - Spin correlation in Randall-Sundrum model I and Little Higgs model

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