Top quark spin correlations in theories with large extra dimensions at LHC

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Decay of top quark

$t \rightarrow b + W^+$ – 98.8 %

$W^+ \rightarrow \bar{d} + u$, $\bar{s} + c$, ... } 67.6 %

$e^+ + \nu_e$, $\mu^+ + \nu_\mu$ } 21.6 %

$\tau^+ + \nu_\tau$ – 10.8 %

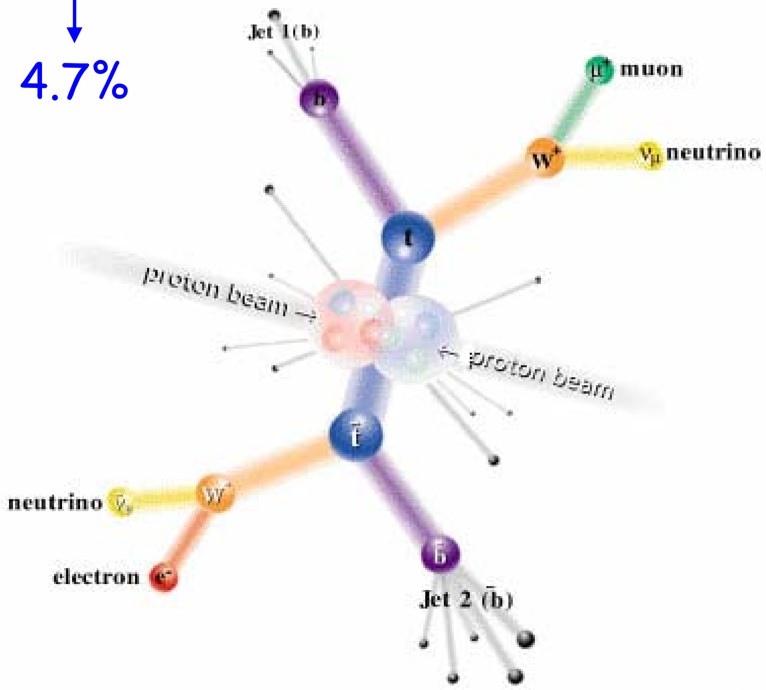
$\tau^+ \rightarrow e^+ + \nu_e + \nu_\tau$, $\mu^+ + \nu_\mu + \nu_\tau$ } 35.2 %

...

$$t \rightarrow b + W^+ \rightarrow \begin{matrix} e^+ \\ \mu^+ \end{matrix} + \nu$$

$$\bar{t} \rightarrow \bar{b} + W^- \rightarrow \begin{matrix} e^- \\ \mu^- \end{matrix} + \bar{\nu}$$

4.7%



Polarization of top quark

It is possible to study the polarization of top quark using the decay products:

$$\frac{1}{N}\frac{dN}{d\cos\theta_f} = \frac{1}{2}(1 + \alpha_f \cos\theta_f)$$

The angle between the direction of particle *f* in the top rest frame and the direction of top quark spin.

-0.41 for b
0.41 for W^+
0.35 for jet
1.0 for e^+, μ^+

- At LHC top (antitop) quarks are produced as the helicity eigen-states.
- Top and antitop quarks are produced as unpolarized – the same number of left- and right-handed top quarks.

Spin correlation of top-antitop pairs

The number of ttbar pairs with the same and opposite helicity is not the same.

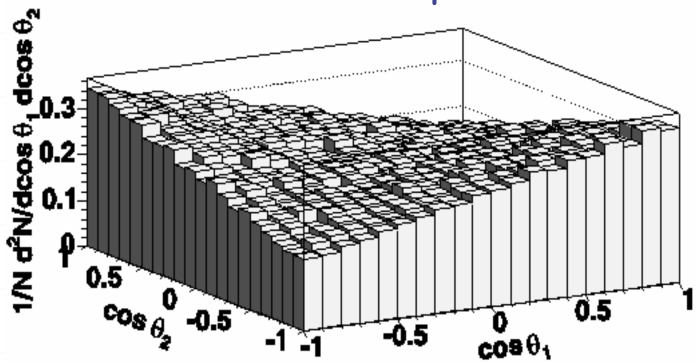
$$A = \frac{\sigma(t_\uparrow \bar{t}_\uparrow)+\sigma(t_\downarrow \bar{t}_\downarrow)-\sigma(t_\uparrow \bar{t}_\downarrow)-\sigma(t_\downarrow \bar{t}_\uparrow)}{\sigma(t_\uparrow \bar{t}_\uparrow)+\sigma(t_\downarrow \bar{t}_\downarrow)+\sigma(t_\uparrow \bar{t}_\downarrow)+\sigma(t_\downarrow \bar{t}_\uparrow)} \neq 0$$

The double differential angular distribution of top and anti-top decay products:

$$\frac{1}{N}\frac{d^2N}{d\cos\theta_f \, d\cos\theta_{\bar{f}}} = \frac{1}{4}(1 - A\underbrace{|\alpha_f \alpha_{\bar{f}}|}_{=1 \text{ for double-lepton channel}} \cos\theta_f \cos\theta_{\bar{f}})$$

SM prediction:

$A = 0.319$



Measurement of top-antitop spin correlation in the ATLAS experiment

- F. Hubaut, E. Monnier, P. Pralavorio, K. Smolek, V. Šimák: *ATLAS sensitivity to top quark and W boson polarization in ttbar events*, Eur.Phys.J. C44 (2005) 13-33.
- Semileptonic and dileptonic ttbar channels.

- At LHC, it is possible to increase the assymetry by applying an upper cut on the ttbar invariant mass:

$$M_{t\bar{t}} < 550\ GeV/c^2$$

⇓

$$A = 0.422$$

- Combining the results of both channels allow to measure the SM spin correlation *A* with a 4% precision for 10 fb^{-1}.

ADD model

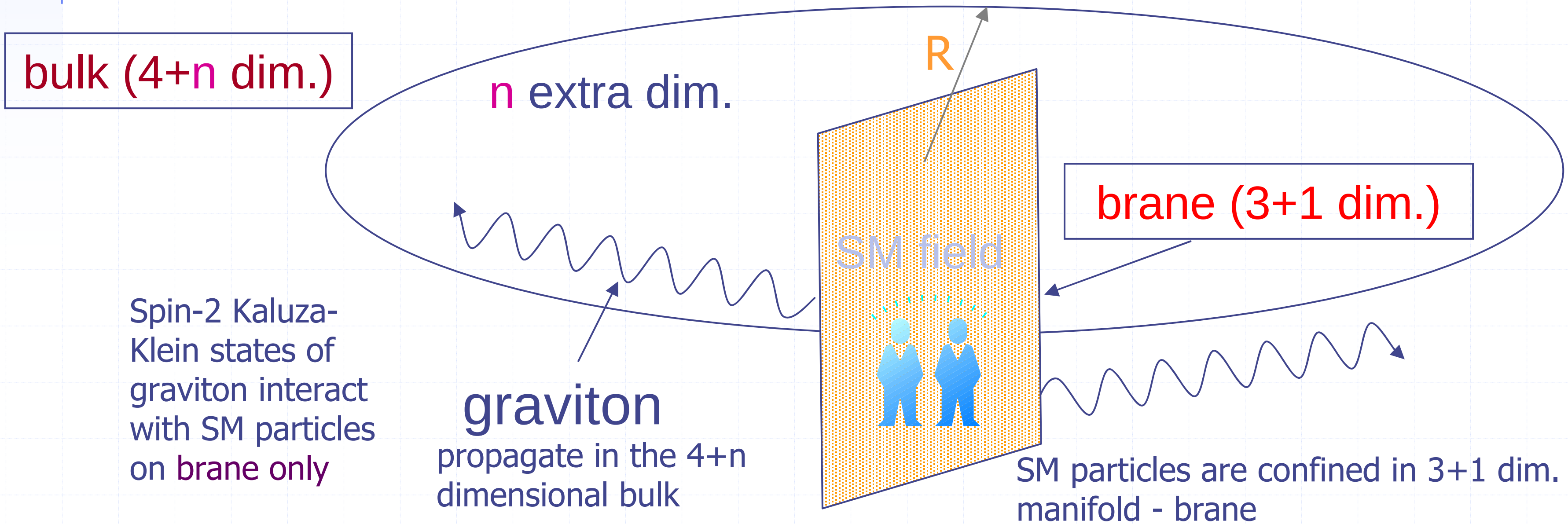
- Theory with n extra-dimensions compactified with large radii.

N. Arkani-Hamed, et al, PLB429 (1998) 263, hep-ph/9803315
I. Antoniadis, et al, PLB436 (1998) 257, hep-ph/9804398

$M_{PL}^2 = M_D^{n+2} R^n$

M_D= low-energy effective string scale (~ 1 TeV)

Např. M_D=1TeV, $M_{PL} = 10^{19}$ GeV, R ~ 1 mm ($0.001 \cdot 10^{-19}$ GeV^{-1}), n = 2

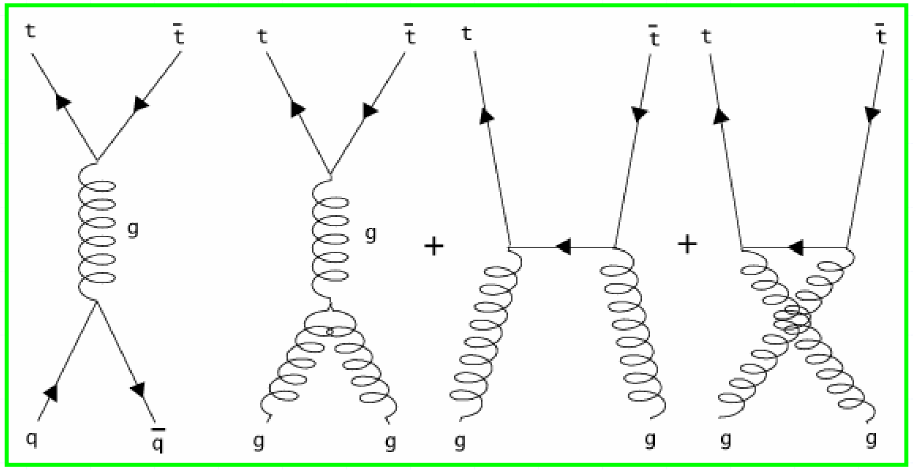


Spin-2 Kaluza-Klein states of graviton interact with SM particles on brane only

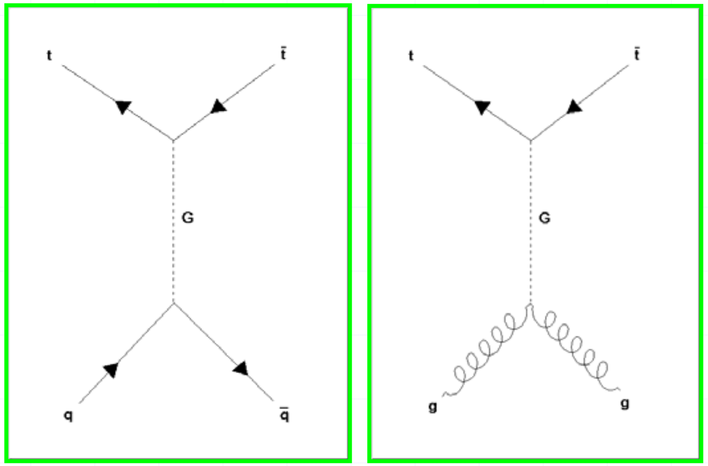
graviton
propagate in the 4+n dimensional bulk

SM particles are confined in 3+1 dim. manifold - brane

ADD model
and top-antitop production at LHC



SM contribution



KK states contribution

2 free parameters:

- M_D - low-energy effective string scale
- λ = §1 – connected to the regularization procedure for the contributions from the infinite number of KK gravitons. λ represents the sign of the interference term between SM and ADD contribution in the $gg \to t\bar{t}$ process.

ttbar production cross section

- Full density matrix:

M. Arai, N. Okada, K. Smolek, V. Šimák: Phys.Rev. D70 (2004) 115015

$$|\mathcal{M}(q\bar{q}\to t_\uparrow\bar{t}_\uparrow)|^2 = |\mathcal{M}(q\bar{q}\to t_\downarrow\bar{t}_\downarrow)|^2 = \frac{g^4}{9}(1-\beta^2)\sin^2\theta + \frac{f_G s^4\beta^2}{2}(1-\beta^2)\sin^2 2\theta,$$

$$|\mathcal{M}(q\bar{q}\to t_\uparrow\bar{t}_\downarrow)|^2 = |\mathcal{M}(q\bar{q}\to t_\downarrow\bar{t}_\uparrow)|^2 = \frac{g^4}{9}(1+\cos^2\theta) + \frac{f_G s^4\beta^2}{2}(\cos^2 2\theta + \cos^2\theta)$$

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

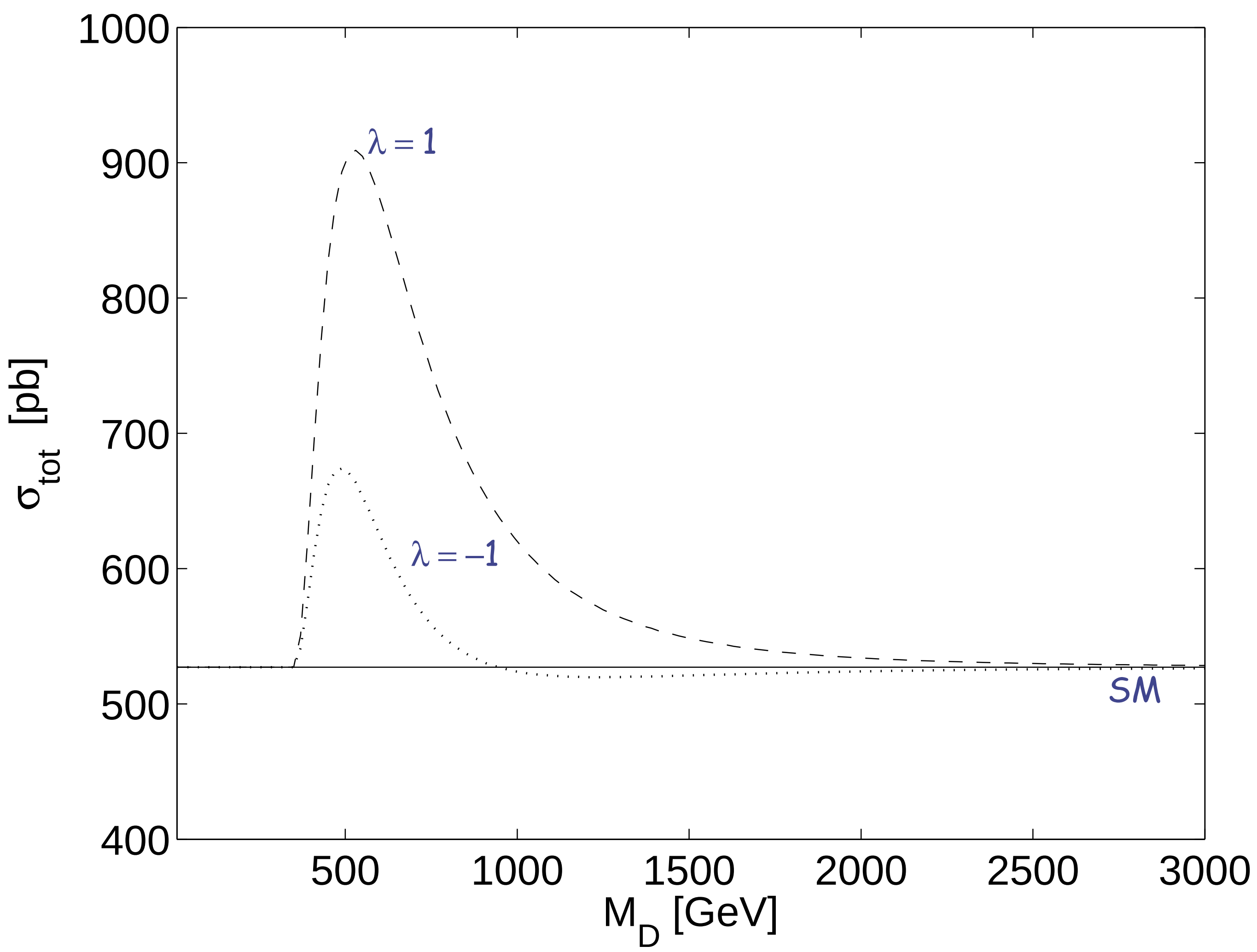
$$|\mathcal{M}(gg\to t_\uparrow\bar{t}_\downarrow)|^2 = |\mathcal{M}(gg\to t_\downarrow\bar{t}_\uparrow)|^2 = \frac{g^4\beta^2}{96}\mathcal{Y}(\beta,\cos\theta)(1+\cos^2\theta) + \mathcal{Z}(\beta,\theta,s) f_G s^2\beta^2\sin^2\theta(1+\cos^2\theta)$$

$$\mathcal{Y}(\beta,\cos\theta) = \frac{7+9\beta^2\cos^2\theta}{(1-\beta^2\cos^2\theta)^2} \qquad \mathcal{Z}(\beta,\theta,s) = \frac{g^2}{4(1-\beta^2\cos^2\theta)} + \frac{3}{4} f_G s^2$$

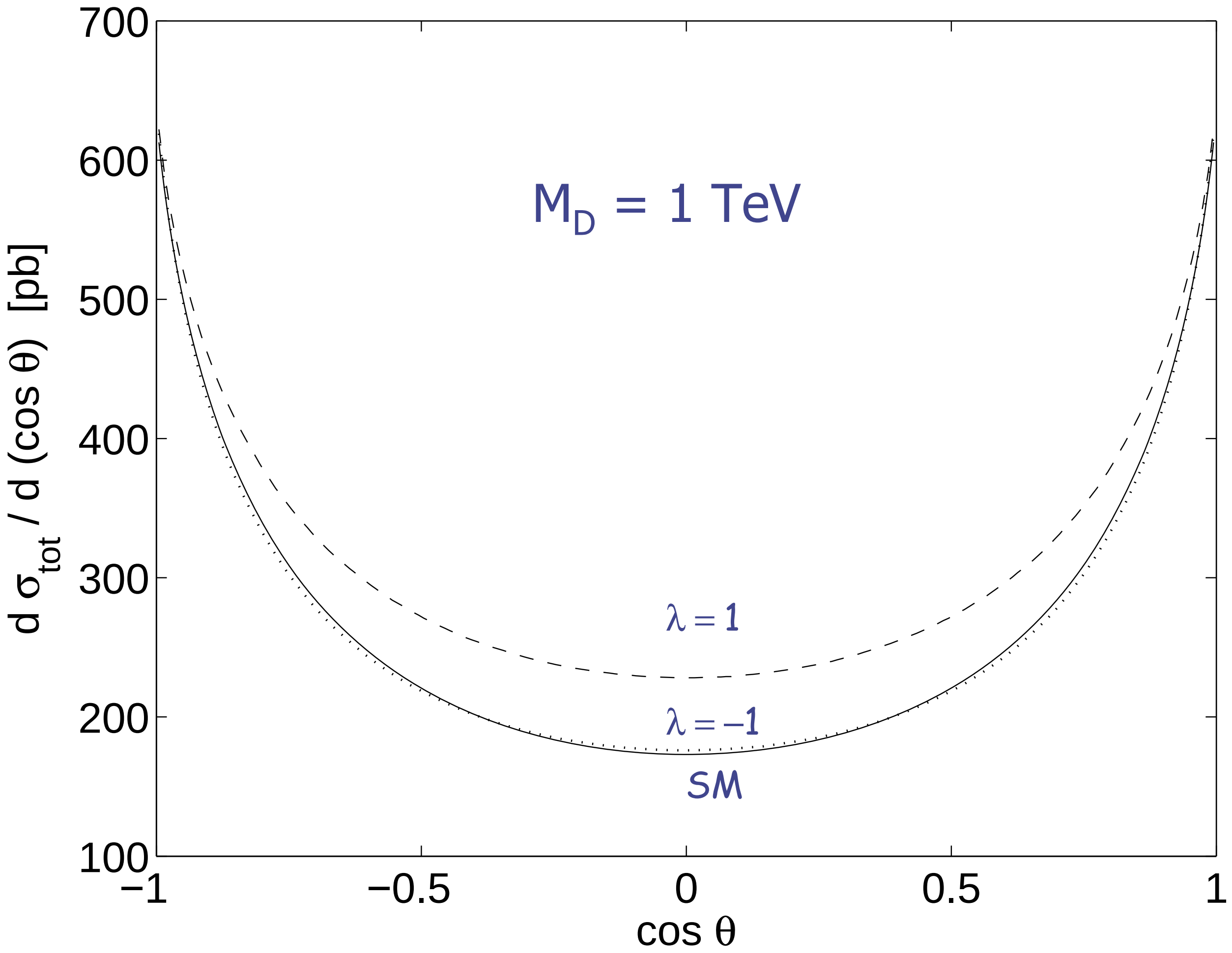
$$f_G \equiv \pi\lambda/2M_D^4 \qquad \lambda = \pm 1$$

$\sqrt{s} < M_D$

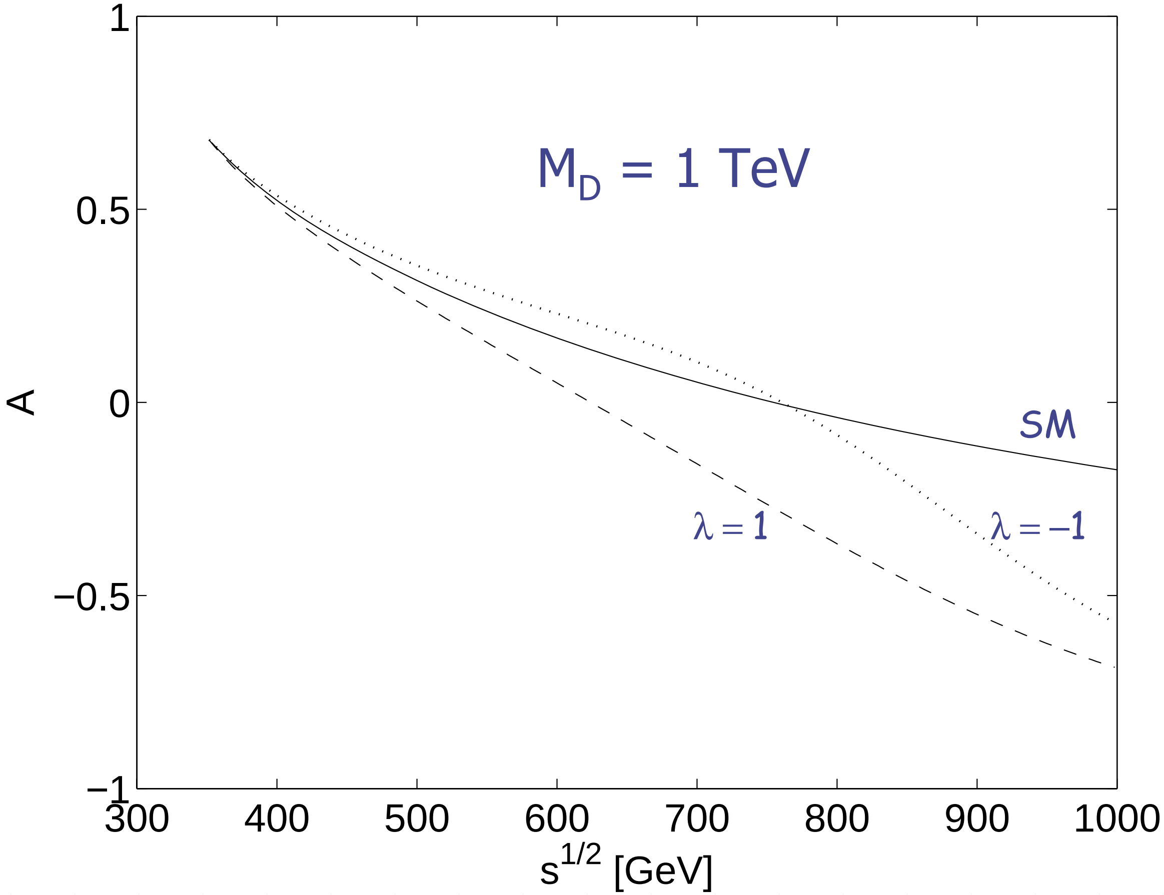
ttbar production cross section



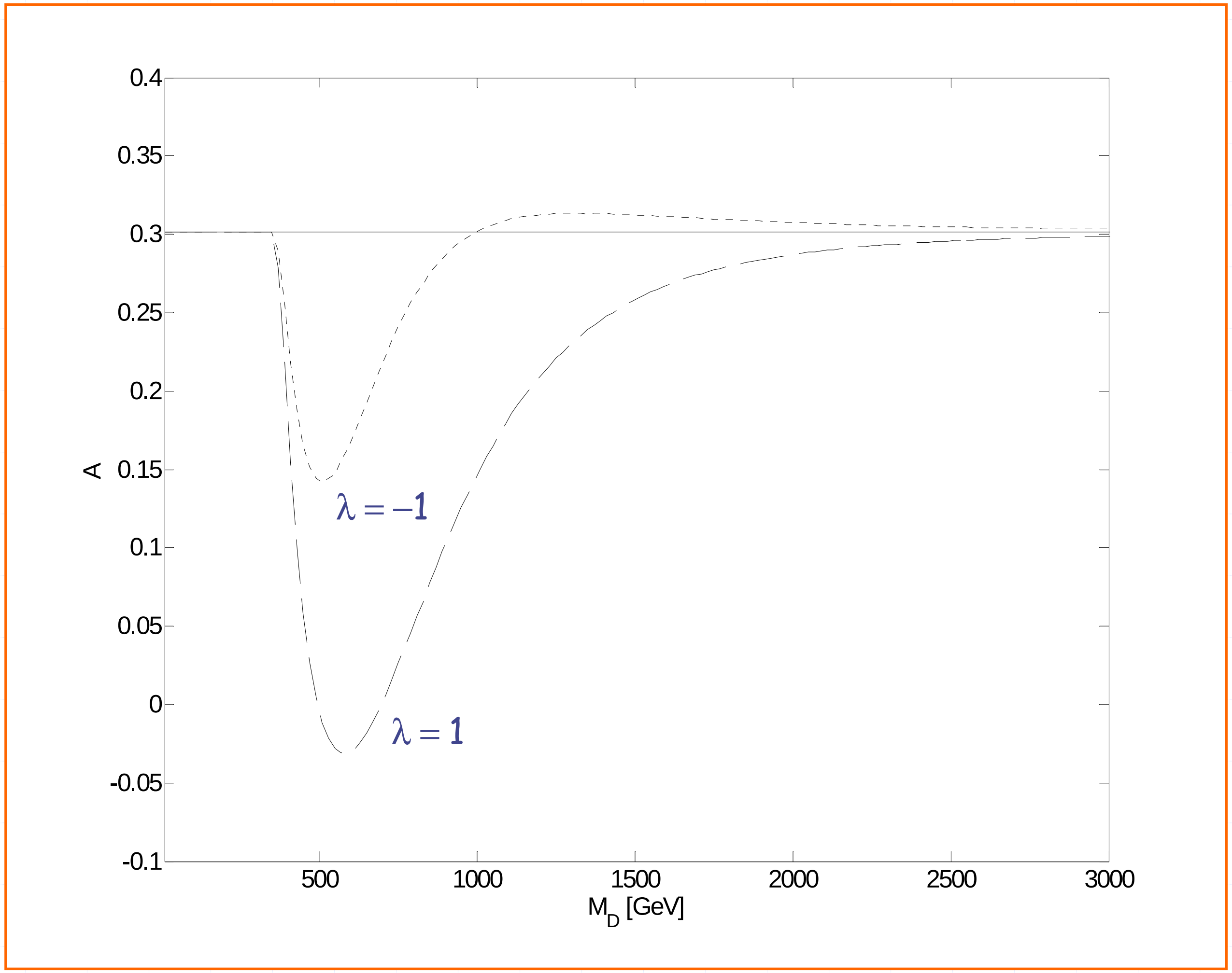
Angular distribution of the top quark



ADD model and spin correlation of top quarks at LHC



ADD model and spin correlation of top quarks at LHC



Conclusions

- Because of its high mass, the top quark is an ideal place to search for physics beyond the SM.
- The ADD model with large extra dimensions is an example of such physics.
- In addition to cross section and various angular distributions, the spin correlation is sensitive to the existence of large extra dimensions.
- The influence of extra-dimensions on the spin correlation of top-antitop quarks could be visible at the LHC in the case the effective scale M_D is lower than ~1.5-2 TeV.

Thank you for your attention