LHC Phenomenology for Resonant Top Pair Production with Extra-Dimensions

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Introduction

While the Standard Model of Particle Physics (SM) has been highly successful in predicting experimental observations, it is not without issue. To resolve these short-comings we may use a 'bottom-up' approach by including additional symmetries. Certain Beyond the SM (BSM) theories extend the symmetry of the SM by allowing extra spatial dimensions. These extra-dimensions are necessarily compactified. Certain models attempt to address the hierarchy problem by allowing only certain gauge sectors to propagate in the bulk. This leads to new possible quasi-degenerate resonances in collider experiments. The phenomenological consequences of such a model are explored.

$t\bar{t}$ at the LHC

- $t\bar{t}$ is a promising channel at the LHC, with a good signal to background ratio.
- Dominant uncertainties come from b-tagging, jet energy scale and boosted top identification.
- Since, $\Gamma_t > \Lambda_{QCD}$: the top quark decays more rapidly than it hadronizes.
- Consequently, additional information e.g. spin is inherited by its decay products.
- Hence, we can make use of Asymmetry observables.

Extra Dimensions

- A large amount of theoretical and phenomenological literature exists which place all, or some, SM fields in the bulk.
- A higher-dimensional theory with compact dimensions may be viewed in 4-dimensions by Kaluza-Klein (KK) reduction.
- For example, a scalar field in 5d, compactified on S_1, can be recast with the KK-ansatz

$$\Phi(x, y) = \frac{1}{\sqrt{2\pi R}} \sum_n \phi^{(n)}(x) \exp\left(i\frac{2\pi n}{R}\right).$$

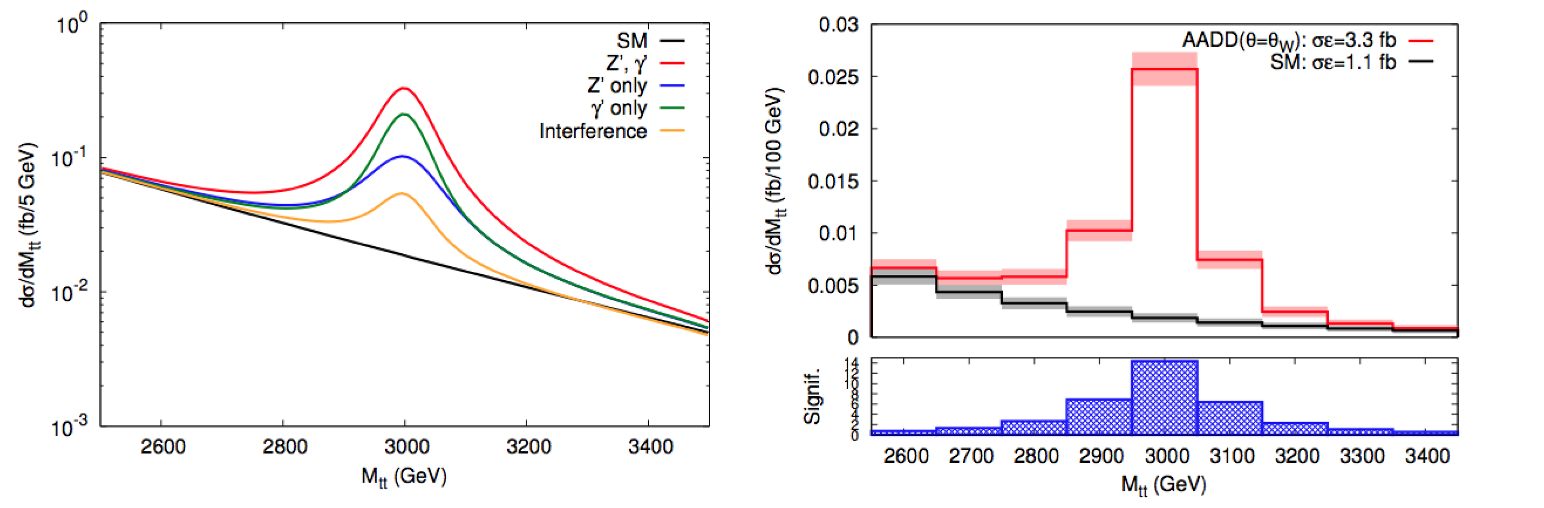
- 4d fields manifest as the coefficients of an infinite sum of Fourier modes with a quantised mass spectrum

$$m_n^2 = m^2 + \frac{n^2}{R^2}.$$

- For large enough extra dimensions this leads to quasi-degenerate resonances.
- The phenomenological effects of extra dimensions have been explored in the context of the AADD model, which shows preferential coupling to $t\bar{t}$ [1].

Off-diagonal Propagator Effects

- Due to quasi-degenerate resonances, significant tree-level interference and one-loop mixing effects both occur.
- The signal no-longer appears as a Breit-Wigner resonance [3].
- An example of this within the frame-work of the AADD model is shown below for the cross section.



The $t\bar{t}$ invariant mass (M_{tt}) distribution of the cross section for the AADD model with $R^{-1} = 3$ TeV. The left figure highlights the contributions from the two resonances and their interference. The right figure shows the observables as they would be observed at the LHC at 14 TeV, with 100 fb^{-1} of integrated luminosity, incorporating a 10% reconstruction efficiency on the $t\bar{t}$ system and statistical uncertainties.

Conclusions and Further Work

- For models, such as AADD, with small mass splitting, we must include both tree-level interference and one-loop mixing effects. We plan to investigate other models offering similar features.
- By exploiting the correlation between charge and spin polarisation asymmetry observables in $t\bar{t}$, we can identify the presence of quasi-degenerate states in a resonant signal at the LHC.
- In future, we will perform a full chain of event generation, (anti)top decay, showering and hadronisation, culminating in a detector simulation. Such, results will be directly applicable to ATLAS BSM searches.

Asymmetry Observables at the LHC

- Asymmetry observables provide additional information about new resonances.
- They reduce uncertainty by taking the ratio of events.
- Can be exploited to distinguish models with degenerate resonances from those containing a single resonance.
- Two classes are charge and spin asymmetry observables.

The AADD Model

- The Antoniadis, Arkani-Hamed, Dimopoulos, Dvali model (AADD) is a Non-Universal Extra-Dimensional theory (NUED). It is motivated in [2].
- In AADD the SM Electro-Weak (EW) sector is allowed to propagate in the bulk, while the colour sector is localised to the 4D brane ((t, l, l) realisation).
- Hence, EW gauge bosons gain KK excitations $\tilde{\gamma}'$ and $\tilde{Z}'$ with an enhancement of $\sqrt{2}$ to their SM gauge quantum numbers.
- We define asymmetry observables A_{FB} and A_L:

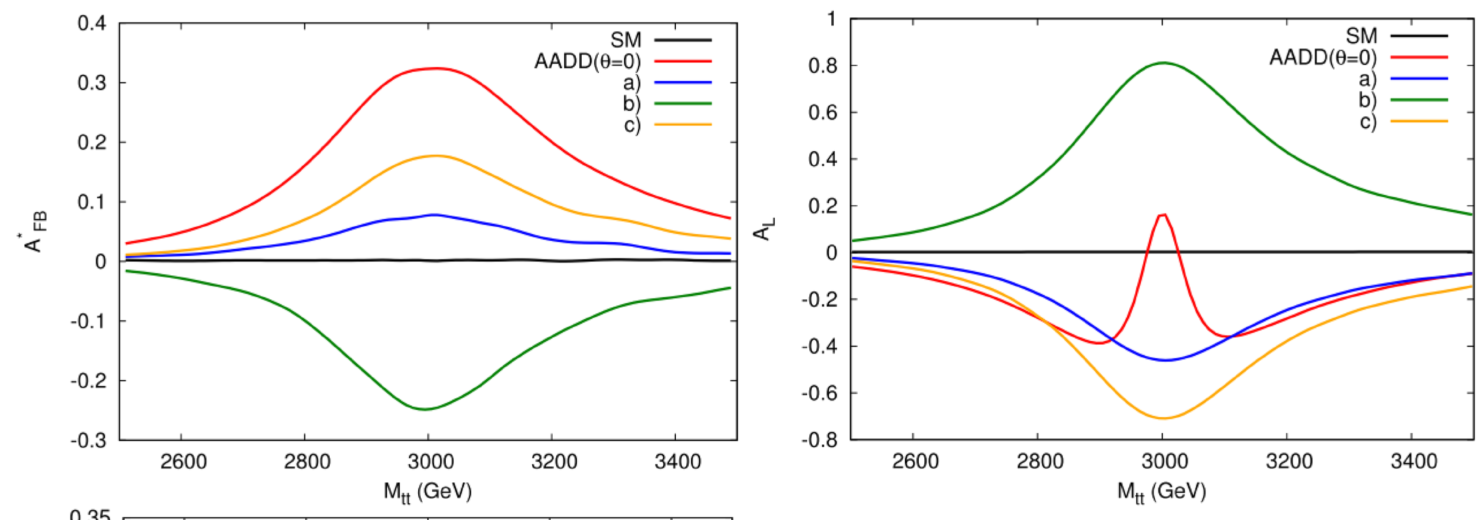
$$A_{FB} = \frac{N_{t(\bar{t})}(\cos\theta^* > 0) - N_{t(\bar{t})}(\cos\theta^* < 0)}{N_{Total}}, \quad A_L = \frac{N(-,-) + N(-,+) - N(+,+) - N(+,-)}{N_{total}}$$

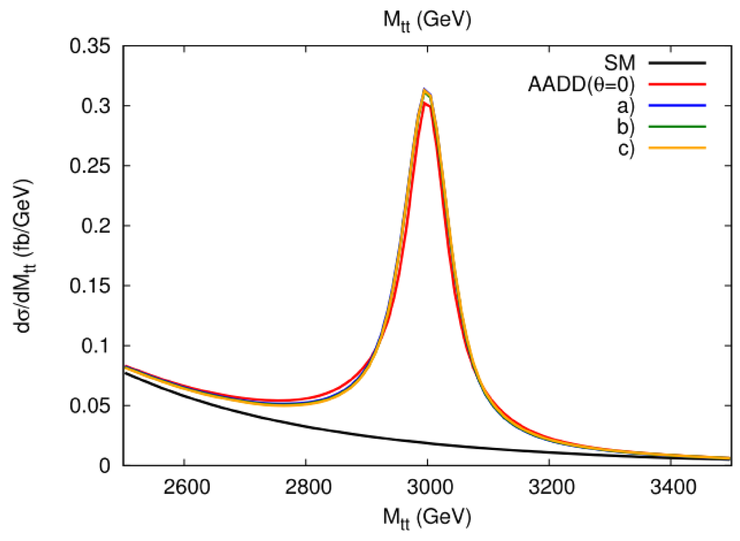
- These observables access a parity asymmetric combination of left and right-handed couplings to the resonances.

$$\sigma \sim \left((q_R^i)^2 + (q_L^i)^2\right)\left(t_R^2 + t_L^2\right)$$
$$A_{FB} \sim \left((q_R^i)^2 - (q_L^i)^2\right)\left(t_R^2 - t_L^2\right)$$
$$A_L \sim \left((q_R^i)^2 + (q_L^i)^2\right)\left(t_R^2 - t_L^2\right)$$

Degeneracy Versus a Single Resonance

- To demonstrate effectiveness of asymmetry observables in distinguishing AADD from a single resonance we create a set of toy models deliberately indistinguishable in a resonance search.
- Assume universal couplings across fermion generations: input only $u_{L,R}$ and $d_{L,R}$.





$\theta = 0$	u_L	u_R	d_L	d_R
a)	0.108	0.186	0.846	1.426
b)	0.242	0.064	0.065	1.401
c)	0.149	0.405	0.292	0.502

Differential distributions in M_{tt} for σ, A_L and A_{FB}^* comparing the AADD with three selected scan points modelling a single resonance with random couplings generated with its widths fixed to match the cross section of each case of AADD. The randomly chosen couplings are summarised in the lower right table.

References

1 E. Accomando, K. Mimasu and S. Moretti. Uncovering quasi-degenerate Kaluza-Klein Electro-Weak gauge bosons with top asymmetries at the LHC. *arXiv:1304.4494v2 [hep-ph], 28 Jun 2013.*
2 E. Accomando, I. Antoniadis and K. Benakli. Looking for TeV-scale Strings and Extra-Dimensions. *Nucl. Phys. B579 (2000) 3-16*
3 G. Cacciapaglia, A. Deandrea and S. De Curtis. Nearby resonances beyond the Breit-Wigner approximation. *Phys. Lett. B 682 (2009) 43-49*

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