Testing the Extended Randall-Sundrum Model using Same-Sign Dilepton Channels

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Abstract

This study focuses on studying certain same-sign dilepton channel processes that could provide evidence for a higher dimensional universe as proposed by the extended Randall-Sundrum model. There are several processes and channels that provide evidence for this 5-dimensional behavior, but we focused on one specific channel involving a Kaluza-Klein W boson that decays into a Radion and a SM W boson, eventually resulting in a di-lepton and di-jet final state. To carry out our study we used tools such as MADGRAPH, Python, ROOT, and the UMD T3 Computing Cluster.

Randall-Sundrum Model

The Randall-Sundrum (RS) model is a physical model that postulates our universe as a five-dimensional expanse, with our observable universe being a four-dimensional cross-section, or "brane", of the five-dimensional "bulk". In the RS model, there are two branes (IR or TeV and UV or Planck brane). Fields have characteristic wave functions in the bulk. Gravity is localized on the Planck brane while the Higgs field is localized at TeV brane. Other SM fields like gauge fields are flat along the extra dimension and light fermions are peaked at the Planck brane. The RS model uses this to attempt to resolve the "hierarchy problem." The overlap of the 5-D profile of each particle with the Higgs at the TeV brane determines a particle's mass. The extended RS model has three branes, with different fields propagating in different bulks (shown in figure below). The extended region contains SM electroweak gauge bosons as well as the radion, a spin-0 particle looked at in this study, which corresponds to the fluctuation in size of the extra dimension.

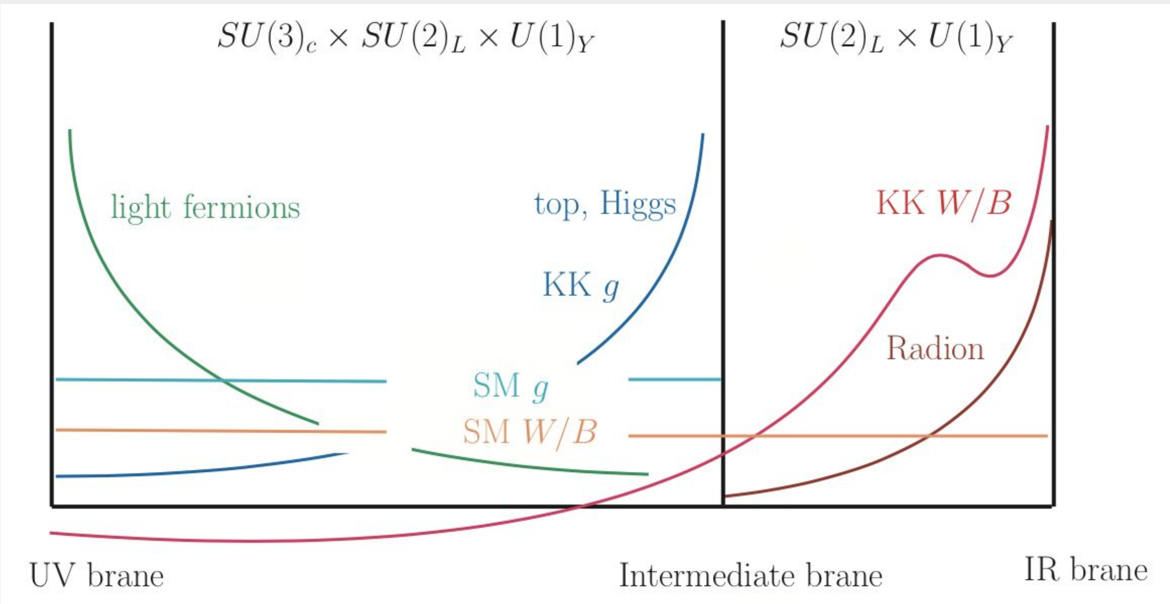

Figure 1. Diagram of the Extended RS Model [2]

Methodology

Our analysis involved running simulated processes using the physics of the extended RS model to see if we could find evidence of new physics when we compared our signal to various SM backgrounds. Using MADGRAPH as our simulator, we imported a new model into that exposed MADGRAPH to certain new particles and couplings postulated by the extended RS model. We then used Delphes for our detector simulation and Pythia to take care of parton distribution and shower simulation. Cuts were used to increase the statistical significance of our signal process against SM backgrounds (Figure 2).

1. Proton-proton collision forming Kaluza-Klein W boson (signal)
2. Proton-proton collision forming 3 SM W bosons (bk)
3. Proton-proton collision forming 2 SM W bosons and two jets (bk)

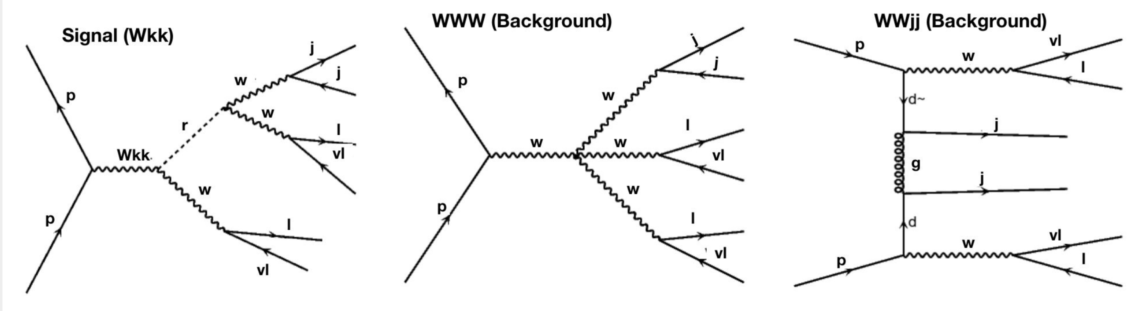

Figure 2. Representative Feynman diagrams for each process

Results

10^4 events were simulated, for the signal process and for each background process. Preselection cuts were applied for events with values for kinematic variables within certain constraints. The preselection cuts applied can be found in the table below (left). During analysis, further cuts were applied for the purpose of limiting the events to a range of kinematic variables in which the signal process is significantly distinct from the background processes, in the simulated events. The cuts applied during analysis can be found in the table below (right), with the associated cross sections and numbers of real events, using luminosity of 300 fb^{-1}.

Preselection Cuts
$\eta_j < 3$
$\eta_\ell < 2.5$
$\Delta R_{\ell\ell} > 0.4$
$\Delta R_{j\ell} > 0.4$
$p_{T_j} \geq 20$ GeV
$p_{T_\ell} \geq 10$ GeV

Table 1: Preselection cuts

Cut Flow	Cross-section (fb)			Real Events		
	S	B_1	B_2	S	B_1	B_2
1. Preselection Cuts	0.0364	1.10	3.54	10.9	329	$1.06 * 10^3$
2. $MET > 175$ GeV	0.0299	0.0597	0.397	8.97	17.9	119
3. $M_{\ell\ell} > 175$ GeV	0.0276	0.0235	0.134	8.28	7.05	40.1
4. $p_{T_{\ell 1}} > 200$ GeV	0.0253	0.0111	0.0382	7.60	3.32	11.5

Table 2: Cut flow (S refers to the signal process. B_1 refers to the $p\,p > W^\pm W^\pm W^\mp$ background process. B_2 refers to the $p\,p > W^\pm W^\pm j\,j$ background process.)

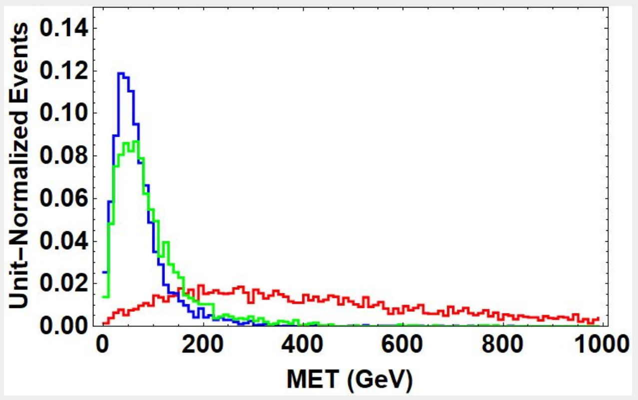

Figure 3. MET for events after pre-selection cuts

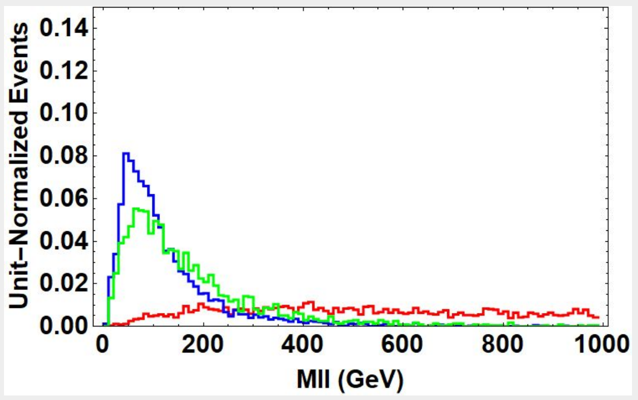

Figure 4. Invariant mass of lepton pair for events after pre-selection cuts

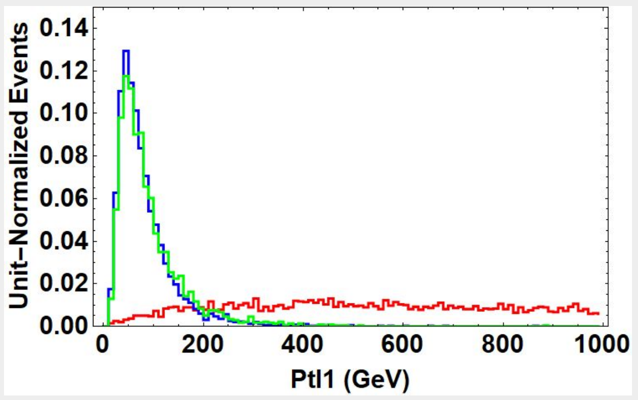

Figure 5. Lesser of the two lepton transverse momenta for events after pre-selection cuts
Key | Signal (red), WWW (blue), WWjj (green)

Conclusions

The final significance value for the cuts performed on the 10,000 simulated events was approximately 1.61. Significance was calculated using $S/\sqrt{S+B}$, where S and B are real signal and background events, respectively. With a projected luminosity of 3000 fb^{-1}, this would result in a significance of approximately 5.08. This would be high enough significance to indicate that this channel would be potentially useful in identifying evidence of physics not accounted for by the standard model. However, luminosity of 3000 fb^{-1} is not currently possible, and is only a projection of hypothetical future development. Given the 300 fb^{-1} luminosity, the significance is not high enough to suggest that same-sign dilepton channels could be potentially used, with the given cuts, to indicate evidence of new physics, although it is perhaps high enough to merit further examination.

References

1) L. Randall and R. Sundrum, Physical Review Letters (1999)
2) K. Agashe, P. Du, S. Hong, and R. Sundrum, Journal of High Energy Physics (2017)
3) K. Agashe, J.H. Collins, P. Du, S. Hong, D. Kim, and R.K. Mishra, Physical Review (2019)