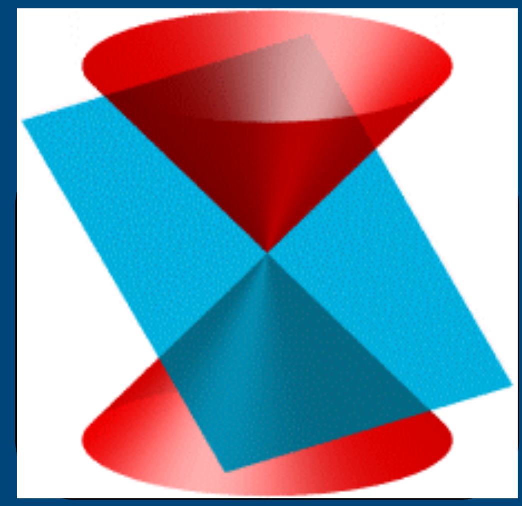
Searches for boosted top quarks at LHC



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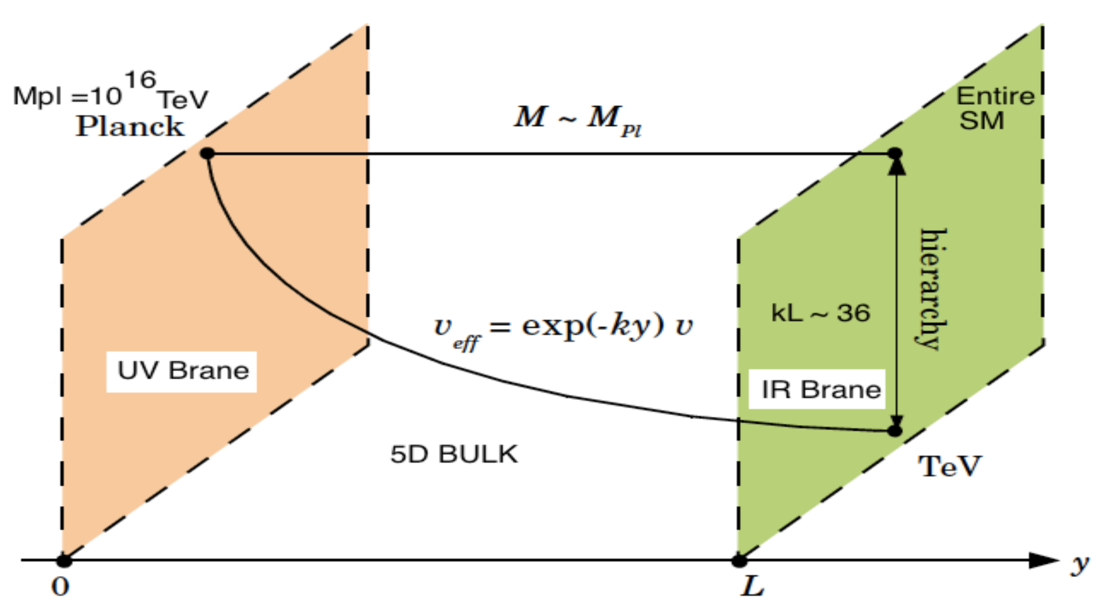
Abstract:

Many beyond-Standard-Model (BSM) theories predict massive new particles. The detection of such massive particles at the Large Hadron Collider (LHC) is very challenging. Heavy mass of these particles ensures their dominant decay to top quarks. The top quarks coming from such massive particles are heavily boosted. Thus, the search for boosted tops allows the detection for these particles.

We have studied the phenomenology of massive first Kaluza Klein (KK) mode for the Higgs boson and the gluon decaying to top quarks in two classes of bulk Randall Sundrum model. We show that such resonances are within the present reach of LHC.

Randall Sundrum Model

The Randall-Sundrum model is a five-dimensional model with a warped metric and was proposed as a solution to the gauge-hierarchy problem. In this model, the fifth dimension y is compactified on an S1/Z2 orbifold of radius, R. There are two branes the UV and the IR brane at fixed points of the orbifold, y = 0 and y = πR ≡ L respectively. In the orginal model all SM fields are localized on the IR brane and only gravitons are allowed to propagate the bulk, which explains the weak strength of gravity due to dilution in bulk volume. In other words we can say that due to the warped factor all mass scales are warped down from Planck brane to TeV(IR) brane as shown below:



Bulk RS Model

The problem with RS Model is that all mass scales on IR brane are warped. Thus the mass scales which suppress dangerous higher dimensional operators responsible for proton decay also become small.

A way out of this is to just localize the Higgs on the IR brane and all the other SM field in the bulk. In fact, even the Higgs need not be sharply localized on the IR brane but only somewhere close to it. In this way, it is possible to make viable variations of the RS model, collectively known as Bulk RS models. These models yield a bonus: localizing fermions at different positions in the bulk gives different overlaps of their profiles with the Higgs giving rise in a natural way to the Yukawa-coupling hierarchy.

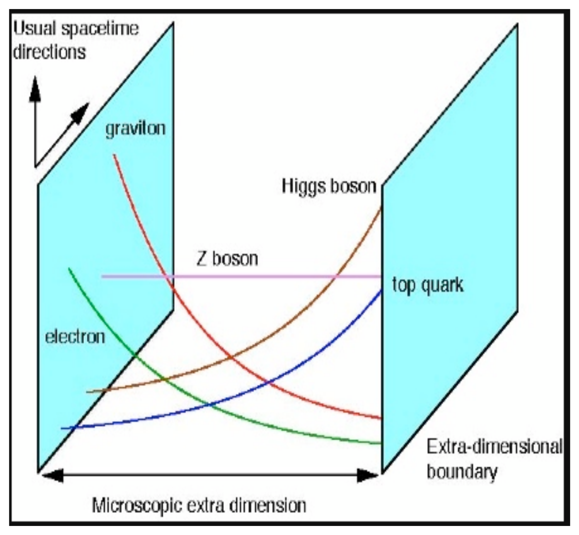
Kaluza Klein Modes and their profiles

The 5D action for a scalar corresponds to a 4D theory with a massless scalar φ (0), called the zero-mode, and an infinite tower of massive modes φ (n), known as Kaluza Klein (KK) modes/ excitations. The KK reduction thus allows a treatment of 5D theories as 4D field theories with an infinite number of fields. A 5D field can be written in a variable separated form in such a fashion that one part is the 4D field and the remaining y dependent part is called the profile of the corresponding field.

Effective couplings in this model are proportional to the profile overlap.

The light quarks are located towards the UV brane away from the higgs , KK modes and the top is located close to IR brane. Thus the overlap of higgs with top quark is more explaining the heavy mass of the top quark.

Also the overlap of KK modes to top quark is more but less to the light quarks .



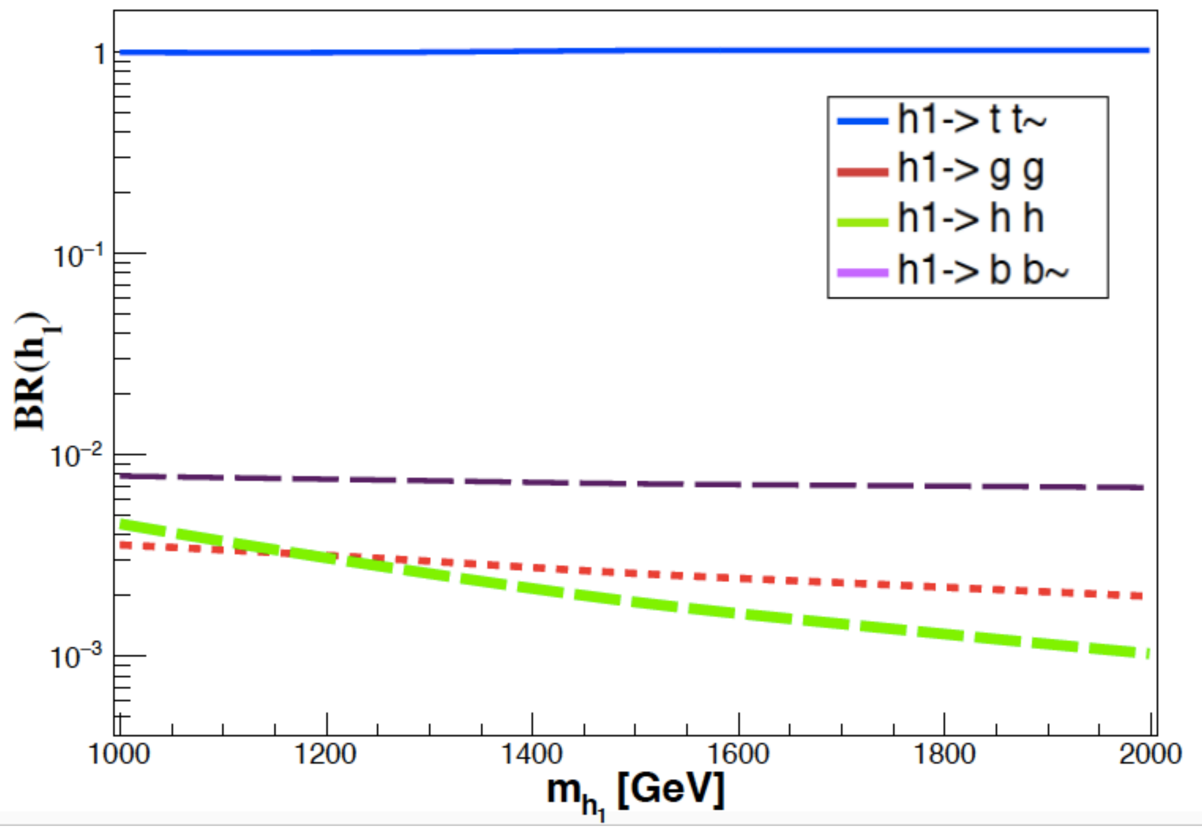
Motivation to study KK Excitations and their decay to boosted tops

In Bulk RS models, the lightest KK excitations are those of the gauge bosons and the higgs boson, searches for these are likely to be the most promising probes of such a model. (Gkk min mass = O(1 TeV))

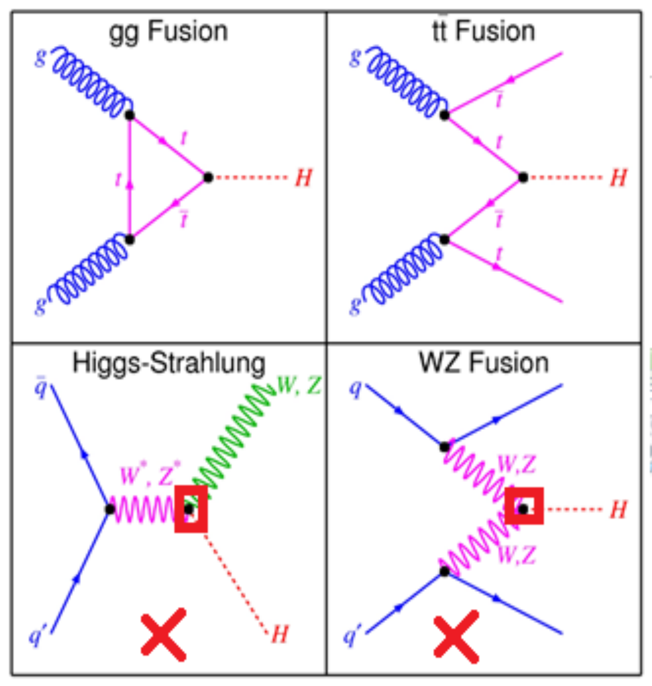
These KK excitations have enhanced coupling to the third generation quarks as both lie closer to IR brane ensuring maximum profile overlap.

As almost all KK excitations are massive enough for the top pair decay channel to be open. These massive KK excitations should dominantly decay into boosted top pairs to prove their existence.

Branching ratio Plot for KK Higgs



Production KK Higgs at LHC



Kaluza Klein modes of the same field are orthonormal to each other. The Higgs vev carries the profile of the Higgs zero mode. So weak boson processes are not able to produce KK Higgs. In SM the Higgs production cross section associated with two tops is very small as compared to gluon fusion. Also, the KK Higgs is heavier than SM Higgs hence its associated production cross section is yet smaller making gluon fusion the main production process at LHC.

Associated Production of KK Gluon at LHC

KK modes of gluon (Gkk) have enhanced coupling to the right handed tops but negligible to light quarks and due to orthogonality gluon gluon intial states at LHC are forbidden to produce Gkk. This leads to very small cross section for resonant production of Gkk. Improvement in cross section is needed in order to be worthy of detection at the LHC this can be done by looking at the alternative production procedure i.e Gkk production in association with one jet diagrams in first row show them along with Gkk production in association with two jets shown in the second row. These sub processes add up enhancing production cross section. Thus making it interesting signal to look for at the LHC.

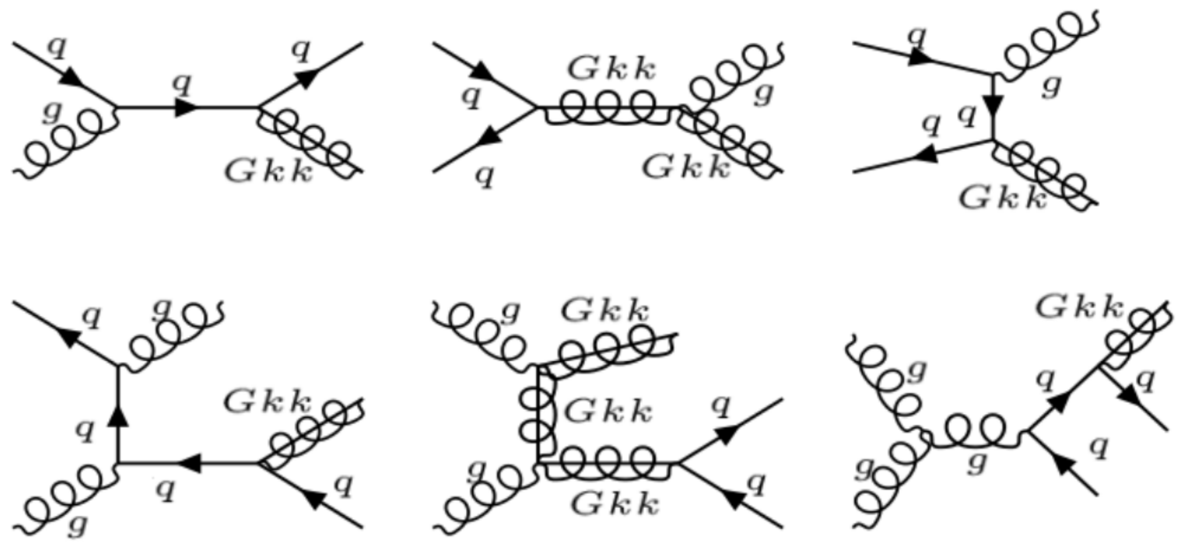
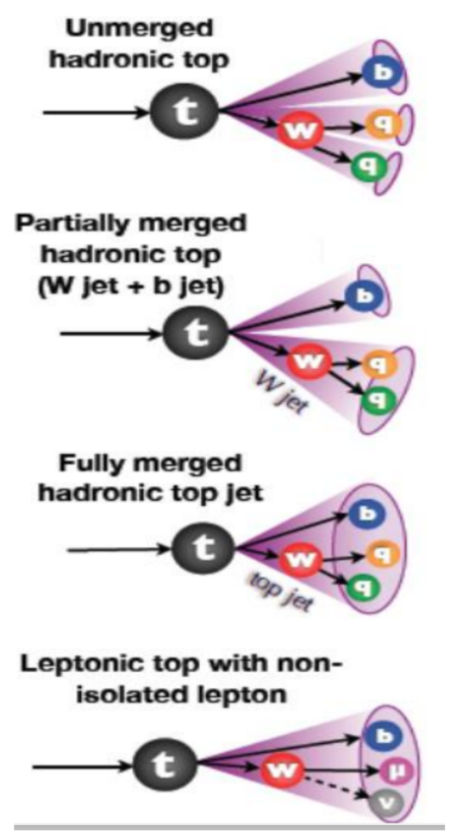


FIG. The subprocesses contributing to g_{KK} production in association with partons.

Analysis strategies for Boosted Tops



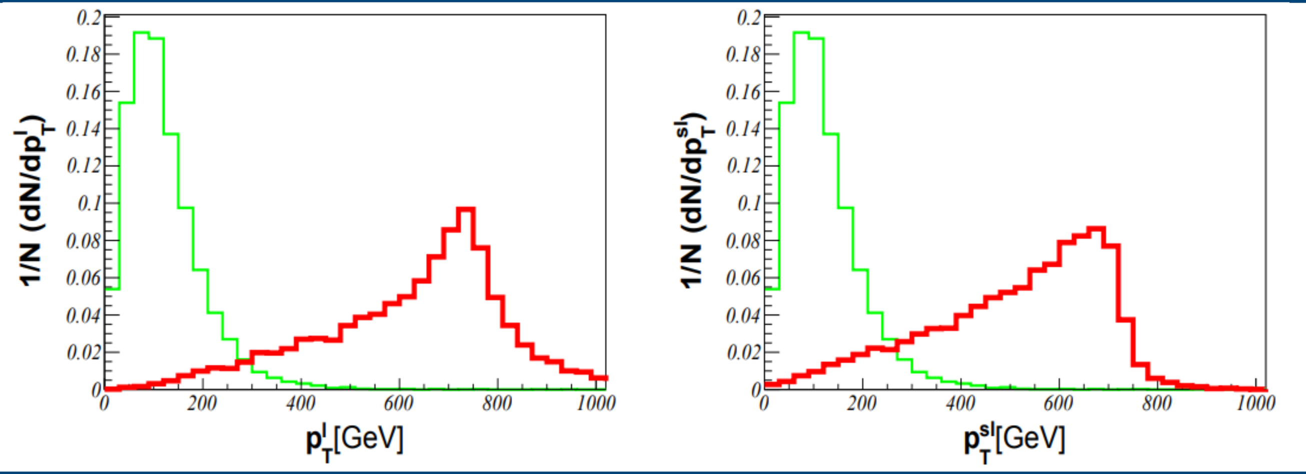
IF 'm' is the mass of the decaying object and pt its transverse momentum, then the radius between its daughter decay particles is given as R= 2m/pt.

Boosted top quarks coming from massive particles have very high pt (nearly equal to half of KK excitation mass) making the decay R less and ensuring the Top quark decay fragments to more or less lie within a single jet called Top jet.

The substructure variables like Nsubjettiness (number prongs inside the jet) and top tagging techniques help enhance signal to background ration. Strategy to be chosen depending on the momentum range in which the top jets lie.

We used Nsubjettiness for KKG (Kaluza Klein gluon first mode)and HEPToptagger for KKH (Kaluza Klein Higgs first mode).

Pt plots of top jets for signal (Red) Vs background (Green)



Results of Simulation

Sr.No	Cuts	QCD($p_T^{sum} > 1250$)	$t\bar{t}jj$($p_T^{sum} > 1250$)	Signal events
1	Given number of Events	10^7	10^5	10000
2	Cross-section(fb)	720×10^3	132	94.2
3	$n_{lepton} = 0$	9203793	39386	3122
4	$p_T^{j_0}$ >1100 GeV	233520	14051	1363
5	Subjettiness cut	262	218	265
6	$\lvert m_{g_{KK}} - 3000\rvert < 80$ GeV	48	55	112

TABLE I: Cut flow table for $m_{g_{KK}} = 3$ TeV.

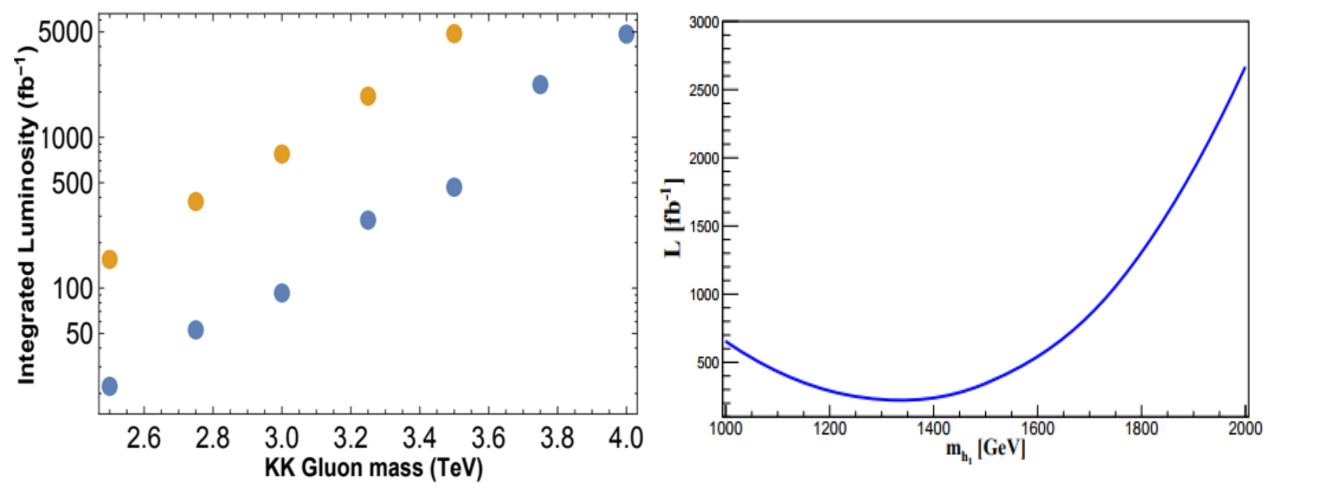
Mass(GeV)	Cuts	Signal(fb)	QCD(fb)	$t\bar{t}$(fb)
1000	2 fat jets(p_T > 250 GeV, R < 1.5)	52.36	395183.24	404.80
	2 top-tagged jets	2.64	65.11	27.04
	p_T^l > 400 GeV and p_T^{sl} > 350 GeV	1.43	58.33	26.66
	$\lvert\Delta\eta\rvert > 1.15$	0.063	10.39	1.24
	900 GeV < m_{tt} < 1100 GeV	0.020	–	0.005
1500	2 fat jets (p_T > 350 GeV, R < 1.5)	4.05	46390.00	91.50
	2 top-tagged jets	0.24	9.24	5.98
	$\lvert\Delta\eta\rvert$ > 1.3	0.06	0.41	0.094
	1350 GeV < m_{tt} < 1550 GeV	0.04	–	0.009

Table 1. *Cut flow table for two values of KK Higgs mass.*

Conclusion

The KK gluon first modes can be probed at the LHC with a luminosity of 1000 fb-1 for deformed RS and 100fb-1 for custodial RS with a mass around 3TeV.

The KK Higgs first modes can be probed at the LHC with a luminosity of 300 fb-1 for custodial RS with mass around 1.2 TeV.



References

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[2] F. Mahmoudi, U. Maitra, N. Manglani, and K. Sridhar, A Higgs in warped bulk and LHC signals, JHEP 1611 (2016) 075, [arXiv:1608.07407]