

Sensitivity of the LHC to Kaluza-Klein gluon in two b -jets decay channel

Masato Arai^{1,2,a}, Gi-Chol Cho^{3,b}, Karel Smolek^{1,c}, and Kyoko Yoneyama^{3,4,d}

¹*Institute of Experimental and Applied Physics, Czech Technical University in Prague, Horská 3a/22, Prague 2, Czech Republic*

²*Fukushima National College of Technology, Fukushima, 970-8034, Japan*

³*Department of Physics, Ochanomizu University, Tokyo 112-8610, Japan*

⁴*Department of Physics, Bergische Universität Wuppertal Gausstasse 20, D-42119 Wuppertal, Germany*

Abstract. We study a possibility of observation of the first Kaluza-Klein (KK) excitation of gluon in a warped extra dimension model at the LHC. In our analysis, we adopt the KK gluon mass and the b -quark coupling to the KK gluon as model parameters and study the sensitivity of the ATLAS experiment to observe the KK gluon through the two b -jets channel.

1 Introduction

Although the Standard Model (SM) of particle physics has shown a good agreement with almost all data of high energy experiments, we expect new physics beyond the SM from some theoretical motivations such as a gauge hierarchy problem. A warped extra-dimension model proposed by Randall and Sundrum (RS) [1] is one of the promising candidates to explain the hierarchy between the Fermi scale and the Planck scale. We suppose the extension of the original RS model, where SM gluons can propagate into the bulk. In such a model, there are Kaluza-Klein (KK) excitations of gluons.

We study a possibility of observation of the first KK excitation of gluon at the LHC. In our analysis, we adopt the KK gluon mass and the b -quark coupling to the KK gluon as model parameters and study the sensitivity of the ATLAS experiment to observe the KK gluon through the two b -jets channel. More detailed description and analysis is published in our paper [2].

2 Randall-Sundrum model

In the RS model, there are two 3-branes which are located in different positions in an extra dimension. One of the 3-branes is called a “visible brane” in which the SM particles are confined while the other is called a “hidden brane”. A graviton is allowed to propagate between two branes. With this set-up, the Higgs boson mass can be electroweak scale naturally when the fifth dimension is warped appropriately and the gauge hierarchy problem is understood without suffering from a fine-tuning problem like the SM.

Although it is sufficient to explain the gauge hierarchy problem when only the graviton propagates into the extra dimension, an extension of the RS model, where (some of) the SM particles also propagate into the bulk, has been studied from phenomenological point of view. A generic consequence of such an extension of the RS model is that there are KK excitations of the SM particles. It is, therefore, important to investigate possibilities of production and decay of KK particles at the LHC as a direct test of the model.

3 Our scenario

In our scenario, we assume that the SM Higgs is located at the visible brane, while the other SM fields and gravity are present in the five-dimensional bulk. We are interested in case that the third generation of quarks couples to the KK gluons strongly, compared to the four-dimensional QCD coupling. Under this setup, we study the process $pp \rightarrow g_{KK} \rightarrow b\bar{b}$, where g_{KK} is the first excitation mode of the KK gluon.

We consider the following scenarios with various values of couplings between the KK mode of gluon and quarks:

$$\frac{g_{Q_3}^{(1)}}{g_4} = \frac{g_t^{(1)}}{g_4} = \frac{g_b^{(1)}}{g_4} = 4, \quad \frac{g_{\text{light}}^{(1)}}{g_4} = 0, \quad (1)$$

$$\frac{g_{Q_3}^{(1)}}{g_4} = 1, \quad \frac{g_t^{(1)}}{g_4} = \frac{g_b^{(1)}}{g_4} = 4, \quad \frac{g_{\text{light}}^{(1)}}{g_4} = 0, \quad (2)$$

$$\frac{g_{Q_3}^{(1)}}{g_4} = 1, \quad \frac{g_t^{(1)}}{g_4} = 4, \quad \frac{g_b^{(1)}}{g_4} = \frac{g_{\text{light}}^{(1)}}{g_4} = 0, \quad (3)$$

where Q_3 is the third generation of the left-handed quark, t, b are the right-handed top and bottom quarks and “light” means the quarks of the first two generations. In (1), couplings of all the quarks of the third generation to the KK

^ae-mail: masato.arai@fukushima-nct.ac.jp

^be-mail: cho.gichol@ocha.ac.jp

^ce-mail: karel.smolek@utef.cvut.cz

^de-mail: hep.phys.ocha.ac.jp

gluon is strong while the coupling between the KK gluon and the light quarks is vanishing. In (2), the KK gluon strongly couples to the right-handed quarks only. The coupling to the left-handed quark is comparable to the QCD coupling g_4 . In (3), the difference from (2) is to take the KK gluon coupling to the right-handed bottom quark to be zero.

4 Simulation of the model

We simulated signal $pp \rightarrow g_{KK} \rightarrow b\bar{b}$ and possible background processes, initial/final state radiation, hadronization and decays using Pythia 8.160 [3, 4], the Monte-Carlo generator. All samples were generated for pp collisions at $\sqrt{s} = 14$ TeV.

For the simulation of the effects of a detector, we used Delphes 1.9 [5], a framework for a fast simulation of a generic collider experiment. For the jets reconstruction, Delphes uses FastJet tool [6, 7]. In our simulations, we used the data file with standard settings for the ATLAS detector, provided by the tool. We used the k_T algorithm [8] with a cone radius parameter $R = 0.7$. The b -tagging efficiency is assumed to be 40%, independently on a transverse momentum and pseudorapidity of a jet. A fake rate of a b -tagging algorithm is assumed to be 10% for c -jets and 1% for light and gluon jets.

5 Selection criteria

We assume this set of event selection criteria:

1. The event must have exactly 2 b -tagged jets with the transverse momentum $p_T > 100$ GeV, the pseudorapidity $|\eta| < 2.5$ and invariant mass $M_{b\bar{b}} > M_{b\bar{b}}^{\min}$.
2. The event must have no other jet with $p_T > 20$ GeV, $|\eta| < 4.9$.
3. The event must have no electron or muon with $p_T > 10$ GeV, $|\eta| < 2.5$.
4. The reconstructed transverse missing energy of the event $E_T^{\text{miss}} < 50$ GeV.

The criterion no. 1 for sufficiently high $M_{b\bar{b}}^{\min}$ effectively suppresses the QCD background processes. The criterion no. 2 suppresses a top-antitop pair production in both the QCD and the RS model, with the subsequent decay of the top quarks to jets. The criteria no. 3 and 4 effectively suppress other decay channels of a top quark decay.

6 Numerical results

We simulated the signal process for various values of couplings and for the masses of KK gluon between 1 TeV and 1.5 TeV. All presented results are scaled to the luminosity of 10 fb^{-1} .

In the Fig. 1, distributions of a $b\bar{b}$ invariant mass without and with the simulated detector effects and the selection criteria for $M_{g_{KK}} = 1$ TeV and couplings (1)–(3) are presented.

Table 1. The statistical significance S/\sqrt{B} of our model for various values of $M_{g_{KK}}$ and couplings estimated for 10 fb^{-1} .

$\frac{g_{\text{right}}^{(1)}}{g_4}$	$\frac{g_{Q_3}^{(1)}}{g_4}$	$\frac{g_b^{(1)}}{g_4}$	$\frac{g_t^{(1)}}{g_4}$	$M_{g_{KK}}$ [TeV]	S/\sqrt{B} for 10 fb^{-1}
				1.0	7.3 ± 0.5
				1.1	5.0 ± 0.4
0	4	4	4	1.2	3.4 ± 0.3
				1.3	2.3 ± 0.2
				1.4	1.7 ± 0.2
				1.5	1.2 ± 0.2
				1.0	4.4 ± 0.3
				1.1	3.0 ± 0.4
0	1	4	4	1.2	2.0 ± 0.3
				1.3	1.4 ± 0.2
				1.4	0.9 ± 0.5
				1.5	0.9 ± 0.4
0	1	0	4	1.0	0.033 ± 0.003

As a signature of new physics, we use the number of selected events. We estimated number of expected observed signal and background events and the statistical significance S/\sqrt{B} . The results of the simulations are presented in the Table 1. In the presented results, we use the value of $M_{b\bar{b}}^{\min}$, for which the statistical significance S/\sqrt{B} is maximal.

As expected, the deviation from the SM is strongly dependent on the coupling of a right-handed b -quark to a KK gluon. For the first and second set of couplings, the effects of KK gluons could be observable. Due to the extremely low cross-section of the signal process, for the third set of couplings the effects of KK gluons are unobservable.

7 Conclusions

We studied the possibility of observation of effects of the first excitation of a KK gluon, predicted by the extension of the RS model. In our work, we aimed on the final states with two b jets. We prepared appropriate Monte-Carlo simulations of the signal and background processes for the pp collisions with the energy $\sqrt{s} = 14$ TeV at the LHC, simulated the effects of the ATLAS detector and the selection criteria. As a signature of new physics, we used the number of selected events. We studied three scenarios (1)–(3) with various couplings of a KK gluon to b and t quarks. We estimated the significance S/\sqrt{B} of our model. For the integrated luminosity of 10 fb^{-1} , the deviation from the SM could be observable with the significance of several sigmas for the mass of a KK gluon up to 1.5 TeV and scenarios (1) and (2). The effects of a KK gluon in the scenario (3) with vanishing coupling of a KK gluon to a right-handed b quark will not be observable.

8 Acknowledgements

The work of M.A. and K.S. is supported in part by the Research Program MSM6840770029, by the project of International Cooperation ATLAS-CERN and by the project

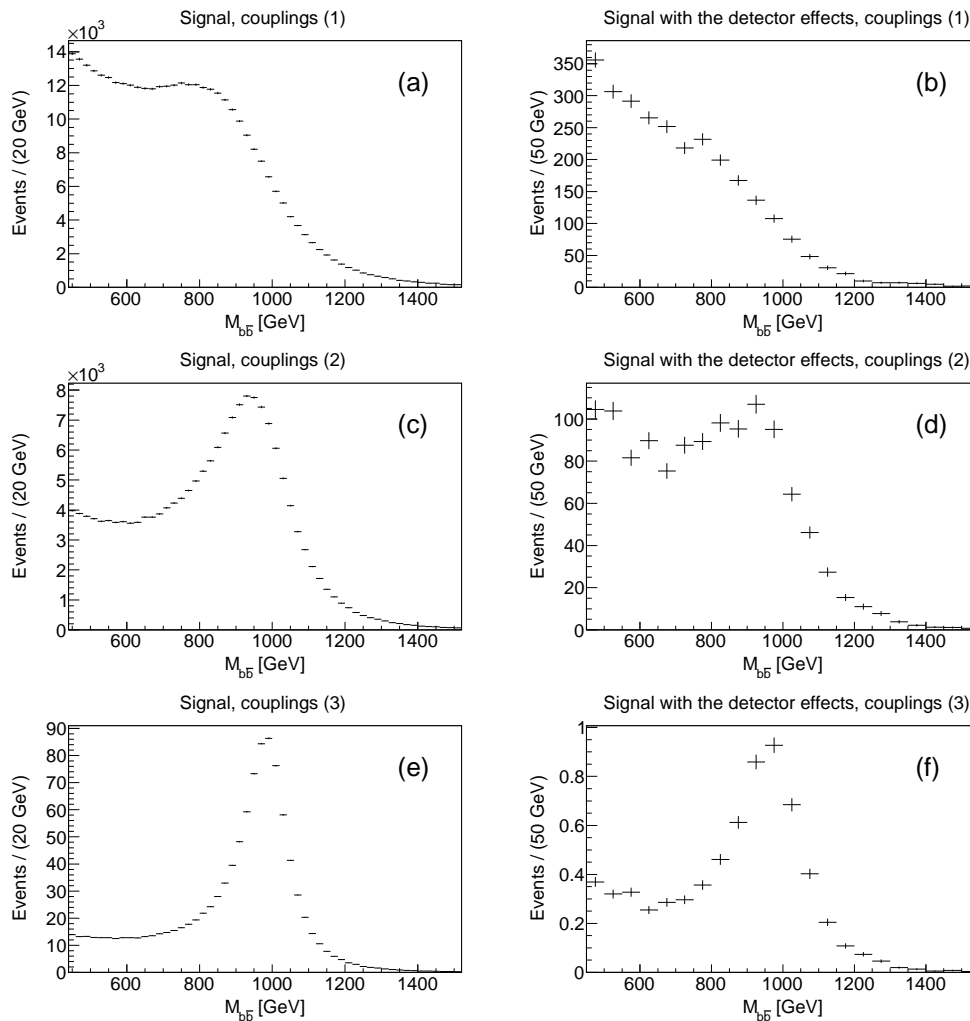


Figure 1. The invariant mass distribution of the $b\bar{b}$ pairs for the signal process $pp \rightarrow g_{KK} \rightarrow b\bar{b}$ without ((a), (c), and (e)) and with ((b), (d), and (f)) the simulated effects of the ATLAS detector and the selection criteria (with $M_{b\bar{b}}^{\min} = 450$ GeV). $M_{g_{KK}} = 1$ TeV was assumed and three scenarios with couplings (1)–(3) were studied (marked as (1), (2), and (3), in the figure). The number of events in the histogram is scaled to the integrated luminosity of 10 fb^{-1} for pp collisions at $\sqrt{s} = 14$ TeV.

LH11106 of the Ministry of Education, Youth and Sports of the Czech Republic. The work of G.C.C is supported in part by Grants-in-Aid for Scientific Research from the Ministry of Education, Culture, Sports, Science and Technology (No.24104502) and from the Japan Society for the Promotion of Science (No.21244036).

References

- [1] L. Randall and R. Sundrum, Phys. Rev. Lett. **83** 3370 (1999); Phys. Rev. Lett. **83** 4690 (1999).
- [2] M. Arai, G.-Ch. Cho, K. Smolek, and K. Yoneyama, Phys. Rev. D **87** 016010 (2013).
- [3] T. Sjöstrand, S. Mrenna and P. Skands, JHEP **05** 026 (2006).
- [4] T. Sjöstrand, S. Mrenna and P. Skands, Comput. Phys. Comm. **178** 852 (2008).
- [5] S. Oryn, X. Rouby, and V. Lemaitre, arXiv:0903.2225.
- [6] M. Cacciari, G. P. Salam and G. Soyez, Eur. Phys. J. C **72** 1896 (2012).
- [7] M. Cacciari, G. P. Salam, Phys. Lett. B **641** 57 (2006).
- [8] M. Cacciari, G. P. Salam and G. Soyez, JHEP **0804** 063 (2008).