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Search for G_{KK} decays to pair of muons at 14 Te

A. A. Abdelalim, R. H. Elkholy, A. F. Hassan
Physics Department, Helwan University, Cairo, Egypt

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The present study is concerned with the Randall-Sundrum (RS) model that predicts the existence of narrow resonances that appear in the di-lipton invariant mass distribution in proton-proton collisions. This gives the final state with di-muon having large invariant mass from the decay of the RS1 graviton. A Large Hadron Collider (LHC) feasibility study for five-sigma discovery at 14 TeV was performed. The Kaluza-Klein graviton (G_{KK}) production cross sections as a function of the graviton mass are presented and the limits on cross sections times branching ratio into muons to observe a 5 σ signal are presented. Our estimates are based on integrated luminosity of 100 fb^{-1} and 1000 fb^{-1}. The conclusion of our study is that the LHC can test the RS1 graviton existence if it is already existing with masses up to 2.6 TeV/c^2 (3 TeV/c^2) at a luminosity of 100 fb^{-1} (1000 fb^{-1}), when the parameter c (model parameter) is equal to 0.01. With the optimistic scenario, at c equal to 0.1, the G_{KK} could be discovered if it is existing with mass up to 5 TeV/c^2 with 100 fb^{-1} and mass up to 6.5 TeV/c^2 with 1000 fb^{-1}.

Keyword: *LHC, Standard Model, New Physics, Narrow Resonances, Randall-Sundrum model*

Introduction

The most successful theory of the up to date particle physics is the Standard Model (SM). It has been tested during the last 30 years by many experiments at Large Electron-Positron collider (LEP), the Stanford Linear Collider (SLC), Tevatron and finally at Large Hadron Collider (LHC). All these experiments are confirming the predictions of the SM with a very high accuracy. Despite this success, scientists common belief is that the Standard Model is not perfect. This belief comes from the unanswered questions which mainly come from cosmological observations that predict the existence of Dark Matter and Dark Energy also from other problems like the hierarchy problem [1] that refers to the large discrepancy between aspects of the weak force and gravity. These problems, with other motivations, were the main motivations for theoretical physicists to invent many proposals for new physics models that are usually called Beyond the Standard Model (BSM) theories. Such models modify the SM in ways to be consistent with the observations from cosmology and neutrino's experiments. In addition, they propose possible answers to other open questions. Moreover, during the last three decades, there were lots of attempts to accommodate the electroweak and the strong interactions in the same framework, to explain the apparent mass hierarchy, to know the source of CP-violation (violation of the charge conjugation parity symmetry) problems, and the flavor mixing arbitrariness and why there are three generations, etc. As one example of the theoretical attempts is the most popular BSM theory is Super symmetry (SUSY).

In the current study, focus will be on theoretical extension other than SUSY. An attractive set of models are the so-called the Large Extra Dimension (LED) and brane world scenarios that

Corresponding author: aabdelalim@zewailcity.edu.eg
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give very clever solution of gauge hierarchy problem and provide "unified" description of the four forces of nature by giving a proper explanation our universe creation and its evolution. The RS model [2] is one of the most popular LED scenarios. The RS model is a 5 dimensional warped geometry model that describes our universe as a warped-geometry of higher dimension universe. In other words, it assumes that the universe is a five dimensional anti-de Sitter (AdS5) space. All elementary particles, except the graviton, are living in 3+1 dimensional brane. The AdS5 geometry has a curvature k that of order of Plank scale, $M_{Pl} \sim 10^{19}$ GeV/c^2, and the metric

$$ds^2 = e^{-k\, r_e\, \varphi}\, \eta_{\mu\nu}\, dx^\mu\, dx^\nu + r_e^{\,2}\, d\varphi^2.$$

where, r_e, is the extra dimension compactification radius, $\eta_{\mu\nu}$ is Minkowski space four dimensional (4D) metric, x^μ are the usual 4D coordinates and finally φ is the new extra dimension. An RS model with only two branes is known as RS1 model [2] where one of the branes with tension σ at $\varphi = 0$ and another brane with negative tension $(-\sigma)$ at distance r_c from the first brane. The RS1 model predicts the existence of Kaluza-Klein graviton modes that would appear at some scale $\Lambda_\pi = M_{Pl}\, e^{-kr_e \pi}$. The zero mode, with $m_0 \sim e^{-k\, r_e}$, is describing the usual 4D gravity and the higher modes are lies with the mass splitting Δm, of order $k \times e^{-k\, r_e}$, between them. The apparent hierarchy between the electroweak and the Plank scales could be removed if $k\, r_e$ is of order about 12. In a model that is considered in the current study, the Kaluza-Klein graviton zero mode can appear as a narrow resonance in the di-lepton distribution at the high p_T range that leads to an excess in Drell-Yan (DY) spectrum with two leptons.

Signal and background simulations

The parameter $c = k/M_{Pl}$ determine the coupling between the graviton and the standard model particles (bosons as well as fermions) hence determines the ability of experimental tests of the RS1 models predictions. Moreover, it determines the width of the resonance $\Gamma \sim \rho\, m_0 c^2$, where ρ is a constant refers to the number of opened decay channels. Theoretically, the allowed range of the coupling constant c is between 0.01 up to 0.1. The graviton resonances can be virtually produced in a quark-antiquark annihilation process $q\bar{q} \rightarrow G_{KK}$ or in a gluon-gluon fusion process $gg \rightarrow G_{KK}$. The quark-antiquark annihilation process is identical to the Drell-Yan in the SM. The second one has an unobserved (so far) process in SM, where the Higgs boson is produced via gluon-gluon fusion and decays to dileptons. Other t-channels sub-processes (like $gg \rightarrow g\, G_{KK}$, $q\bar{q} \rightarrow gG_{KK}$, and $gq \rightarrow qG_{KK}$) also possible via graviton emission. In order to simulate the production of real and virtual graviton at LHC proton-proton collisions with center of mass energy of 14 TeV, PYTHIA8 [3] (proton-proton collision simulator) was used assuming the RS1 scenario. For patron distribution the CTEQ6.6 [4] (patron distribution function for proton structure) functions were implemented. The production cross sections for the G_{KK} with all possible diagrams are shown in Table 1. Two possibilities for the parameter c were assumed. Firstly, the constant c was taken to be equal to 0.1 and secondly c was considered to be equal to 0.01 (the cross-sections shown in the brackets). Where c = 0.1 is the most optimistic scenario and c = 0.01 is the most pessimistic one.

Table (1): G_{KK} production cross-sections [fb]. The CTEQ6.6 [4] parton distributions is used

Mass [TeV/c^2]	1.0	1.5	3.0
$q\bar{q} \rightarrow G_{KK}$	129 (1.34)	23 (0.24)	0.633 (0.01)
$gg \rightarrow G_{KK}$	567 (5.33)	62 (0.53)	0.94 (0.01)
$q\bar{q} \rightarrow gG_{KK}$	345 (3.29)	65 (0.64)	1.84 (0.02)
$qg \rightarrow qG_{KK}$	599 (5.78)	72 (0.64)	1.05 (0.01)
$gg \rightarrow gG_{KK}$	3350 (31.50)	368 (3.33)	4.98 (0.03)
Total	4990 (47.20)	590 (5.38)	9.45 (0.06)

The Standard Model background can be classified into irreducible background in which only the DY process (pp → Z/γ* → $\mu^+\mu^-$) was considered and the reducible backgrounds that includes vector boson pair production (the processes ZZ, WZ, WW), and $t\bar{t}$ production. The reducible backgrounds contributions are measured and could be neglected safely in this study. The detector response simulation for both signal and background was done using DELPHES [5] (simulator for detector responce).

Event selection and Discovery limits

Events with at least two muons are selected only if both muons have pseudorapidity $|\eta| \leq 2.5$, muon system detector acceptance. The DELEPHES card was modified with muon detection efficiency that is shown in the Fig. (1) for a typical efficiency of an LHC experiment. The invariant mass of the muon pairs has to be inside the truth level graviton mass window with width of $\pm 3\Gamma_{obs}$. The Kaluza-Klein graviton production cross section (G_{KK}) and the corresponding limits to observe a 5 σ signal are shown in Fig. (2)assuming two different data sets of 100 fb^{-1} and 1000 fb^{-1}. It is clear from Fig. (2) that the LHC can test the RS1 existence up to masses of 2.6 TeV/c^2 and 3 TeV/c^2 at luminosities of 100 fb^{-1} and 1000 fb^{-1} when the parameter (c = 0.01).

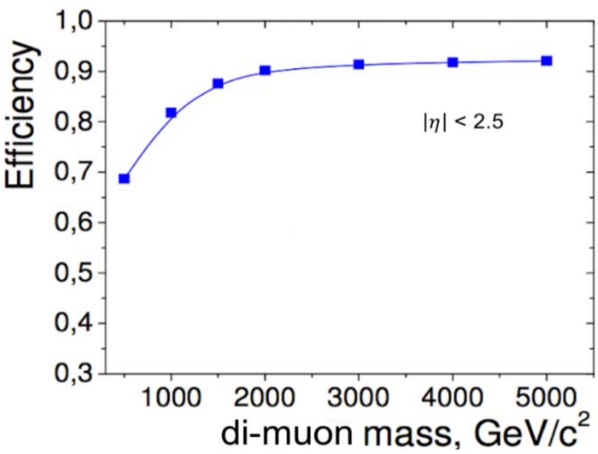

Fig. (1): The di-muon selection efficiency as a function the invariant mass of muon pairs.

With the optimistic scenario, when c = 0.1, the mass region could be extended up to 5 TeV/c^2 with 100 fb^{-1} and up to 6.5 TeV/c^2 with 1000 fb^{-1}. It is known from previous experimental searches, that *c* cannot be less than 0.027 if the graviton mass is around 1 TeV/c^2, and cannot be less than 0.1 if the graviton mass is around 3.7 TeV/c^2. Compared to our results shown in Fig. (2) shows that with a data set of size of about 1000 fb^{-1} (which could be collected in LHC Run III), the whole space of the RS1-model parameters is accessible and that its graviton should be discovered if was there with 5 σ significance.

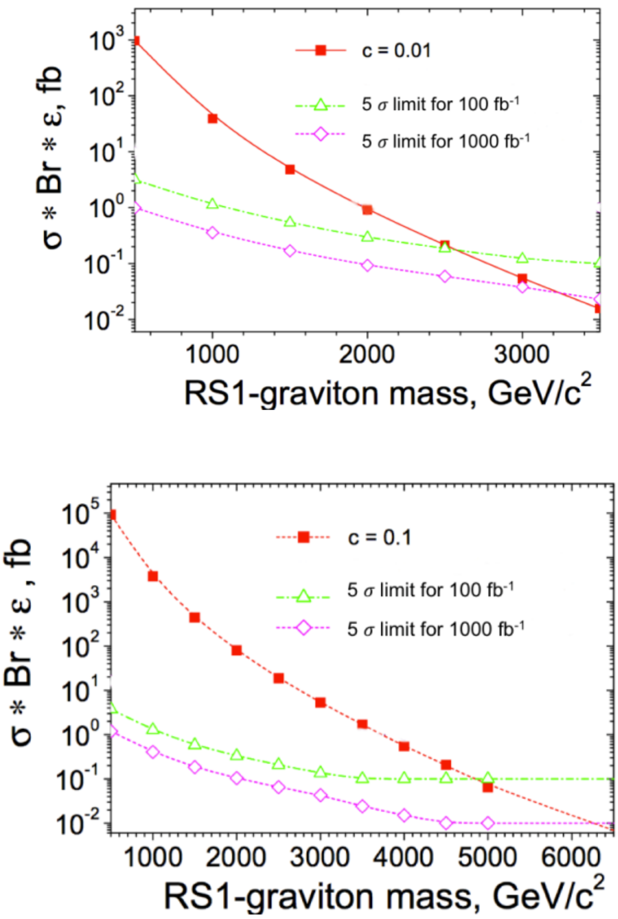

Fig. (2): The production cross sections as a function of the G_{KK} mass at *c* = 0.01 and *c* = 0.1. The limits with 5 σ are also shown with integrated luminosities of 100 fb^{-1} and 1000 fb^{-1}.

Summary

In this paper, the potential of the discovery of RS1 model gravitons in the di-muon channel at the LHC is studied. The proposed estimation for the discovery limit of the zero KK-modes of the RS1 graviton state is about 2.6 and 3.0 TeV/c^2, depending on the model parameter c, for 100 fb^{-1} and 1000 fb^{-1} integrated luminosity.

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