Search for Large Extra Dimensions at the LHC with Center-Edge Asymmetry

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Abstract

We study the possibility of using the center–edge asymmetry to distinguish spin-2 Kaluza-Klein graviton exchange within the ADD scenario from other new physics effects described by spin-1 exchange in lepton-pair production at the LHC. We find that the LHC detectors will be capable of discovering and identifying graviton spin-2 exchange effects in the ADD scenario with M_S ranging from 4.6 TeV to 9.4 TeV depending on luminosity and number of extra dimensions.

1 Introduction

Arkani-Hamed, Dimopoulous, and Dvali have proposed a model (ADD) [1] of low-scale quantum gravity featuring large extra dimensions. In this model, the exchange of Kaluza-Klein (KK) towers of gravitons can enhance the production rate of lepton pairs at high invariant mass in proton-proton collisions at the LHC. The amount of enhancement is characterized by the parameter M_S [2], the fundamental Planck scale in the bulk extra dimensions.

There are several conventions for the parameter M_S. Throughout the paper we will follow the Han, Lykken, Zhang [3] parametrization. The existence of KK gravitons can be tested at colliders by searching for two different

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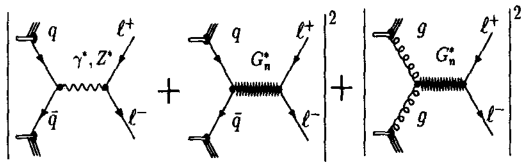

Figure 1: Feynman diagrams for dilepton production at leading order in ADD model.

processes: real graviton emission and virtual graviton exchange. At leading order, virtual graviton exchange includes processes in which a virtual graviton is produced by the annihilation of two SM particles in the initial state, the graviton then propagates in the extra dimension and finally decays into SM particles that appear in the brane. Existing collider experimental data analysis gave no observation of extra dimensions effects, but only constraints. Direct and indirect graviton effects at LEP were searched for in processes of fermion and boson pair production. The corresponding constraints on M_S obtained from LEP and Tevatron data was found to be around 1.3 TeV [4].

We shall here discuss the possibility of distinguishing such effects of extra dimensions from other NP scenarios in lepton pair production at the LHC:

$$p + p \to l^+ l^- + X, \tag{1}$$

where $l = e, \mu$. The dominant Feynman diagrams that contribute to this process in ADD model is shown in Fig. 1.

2 Observables and numerical analysis

In the SM, lepton pairs can at hadron colliders be produced at tree-level via the following parton-level process

$$q\bar{q} \to \gamma, Z \to l^+ l^-. \tag{2}$$

Now, if gravity can propagate in extra dimensions, the possibility of KK graviton exchange opens up two tree-level channels in addition to the SM channels, namely

$$q\bar{q} \to G \to l^+ l^-, \qquad \text{and} \qquad gg \to G \to l^+ l^-, \tag{3}$$

where G represents the gravitons of the KK tower.

The center–edge and total cross sections can at the parton level be defined like for initial-state electrons and positrons [5, 6, 7, 8]:

$$\hat{\sigma}_{\rm CE} \equiv \left[\int_{-z^*}^{z^*} - \left(\int_{-1}^{-z^*} + \int_{z^*}^{1}\right)\right] \frac{d\hat{\sigma}}{dz}\,dz, \quad \hat{\sigma} \equiv \int_{-1}^{1} \frac{d\hat{\sigma}}{dz}\,dz, \tag{4}$$

where $z = \cos\theta_{\rm cm}$, with $\theta_{\rm cm}$ the angle, in the c.m. frame of the two leptons, between the lepton and the proton. Here, $0 < z^* < 1$ is a parameter which defines the border between the "center" and the "edge" regions.

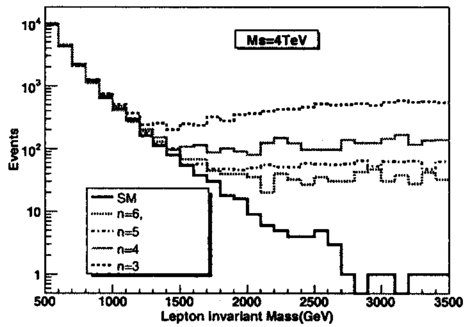

Figure 2: Effects of extra dimensions on the dilepton mass spectrum at LHC. Histograms show the spectrum in the SM as well as in ADD scenario with different number of extra dimensions $n = 3, 4, 5, 6$ at M_S=4 TeV and at integrated luminosity 100 $\rm fb^{-1}$.

The center–edge asymmetry can then for a given dilepton invariant mass M be defined as

$$A_{\rm CE}(M) = \frac{d\sigma_{\rm CE}/dM}{d\sigma/dM}, \tag{5}$$

where a convolution over parton momenta is performed, and we obtain $d\sigma_{\rm CE}/dM$ and $d\sigma/dM$ from the inclusive differential cross sections $d\sigma_{\rm CE}/dM\,dy\,dz$ and $d\sigma/dM\,dy\,dz$, respectively, by integrating over z according to Eq. (4) and over rapidity y between $-Y$ and Y, with $Y = \log(\sqrt{s}/M)$ [6].

As an illustration, Fig. 2 shows the dilepton invariant mass spectrum for the case M_S =4 TeV and for number of extra dimensions $n = 3, 4, 5, 6$

with constructive interference between the SM and KK graviton exchange diagrams. The large extra dimensions signal clearly stands out above the background at higher values of the invariant mass. Fig. 3 shows center-edge asymmetry A_{CE} as a function of kinematical parameter z^* in the SM and ADD scenario. Events predicted by the SM are generated by the PYTHIA 6.325 Monte Carlo (with default PDF CTEQ6L). Everywhere in this study the experimental efficiency is kept at 90%. while ADD expectations were generated by STAGEN 1.05 code.

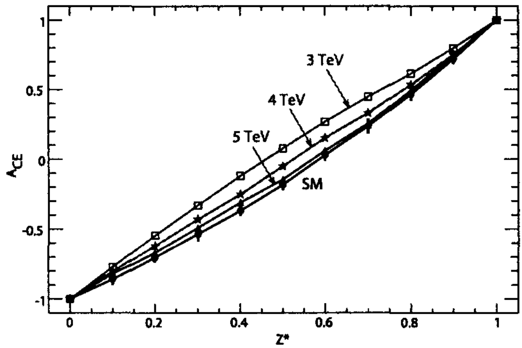

Figure 3: Center-edge asymmetry A_{CE} as a function of kinematical parameter z^* in the SM and ADD scenario with n =5 and M_S = 3 TeV, 4 TeV, 5 TeV .

We assume now that a deviation from the SM is discovered in the cross section in the form of "effective" CI. We will here investigate in which regions of the ADD parameter spaces such a deviation can be *identified* as being caused by spin-2 exchange. More precisely, we will see how the center–edge asymmetry (5) can be used to exclude spin-1 exchange interactions beyond that of the SM. At the LHC, with luminosity $\mathcal{L}_{\text{int}} = 10\ \text{fb}^{-1}$, $100\ \text{fb}^{-1}$ and $1000\ \text{fb}^{-1}$, we require the invariant lepton mass $M > 500$ GeV and divide the data into 100 GeV bins as long as the number of events in each bin, $\epsilon_l \mathcal{L}_{\text{int}} \sigma(i)$, is larger than 10. Here, ϵ_l is the experimental reconstruction efficiency taken as $\epsilon_l = 0.9$ where $l = e, \mu$ and $\sigma(i)$ the cross section in bin i.

In the ADD scenario, the identification reach on M_S can be estimated from the conventional χ^2 analysis [6]. The 95% CL is then obtained by requiring $\chi^2 = 3.84$, as pertinent to a one-parameter fit. The obtained identification reaches are shown in Figure 4.

In conclusion, a method proposed here and based on $A_{\rm CE}$ is suitable for actually *pinning down* the spin-2 nature of the KK gravitons up to very high M_S close to discovery reach. Therefore, the analysis sketched here can potentially represent a valuable method complementary to the direct fit to the angular distribution of the lepton pairs [9, 10] .

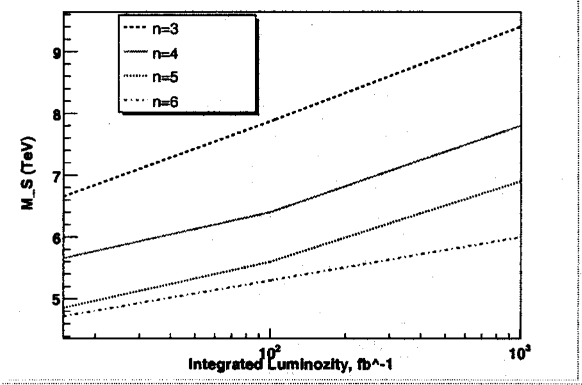

Figure 4: Identification reach on M_S (in TeV) at 95% CL obtained from $pp \to l^+l^- + X$ ($l = e, \mu$) using $A_{\rm CE}$ at LHC.

Acknowledgements
This work is partially supported by the ICTP through the OEA-Affiliated Centre-AC88.

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