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5-dimensional quantum gravity effects in exclusive double diffractive events

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Abstract

The experimentally measurable effects related to extra dimensional gravity in a RS-type brane world are estimated. Two options of the RS framework (with small and large curvature) are considered. It is shown that physical signals of both can be detected by the joint experiment of the CMS and TOTEM Collaborations at the LHC.
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1. Massive gravitons and radion in the RS model

There is no doubt that the discovery of particles like Higgs boson is the fundamental goal, but it will not solve a very important problem of the hierarchy between the electro-weak (246 GeV) and Planck (2.4×10^{18} GeV) scales. Some models have been proposed recently, which resolve the problem without supersymmetry but rather with help of space–time with extra dimensions. For instance, so-called ADD model [1] "explains" the large value of the Planck scale by the large size of compact extra dimensions. Such theories open way for many new experimental studies.

In particular, the model of Randall and Sundrum (RS) [2,3] seems to be the most economic introducing only one extra dimension which has not to be large. It is based on an exact solution for gravity in a five-dimensional space–time, where the extra spatial dimension is a "folded" circle. Let $\{z^M\} = \{(x^\mu, y)\}$, $M = 0, 1, 2, 3, 4$, be its coordinates. Namely, y is the coordinate along the fifth dimension, while $\{x^\mu\}$, $\mu = 0, 1, 2, 3$, are the coordinates in a four-dimensional space–time. The background metric of the model is of the form (contribution of the matter energy–

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momentum tensor is neglected)

$$ds^2 = \gamma_{MN}(z)\,dz^M\,dz^N = e^{2\kappa|y|}\eta_{\mu\nu}\,dx^\mu\,dx^\nu + dy^2. \tag{1}$$

Here $y = r_c\theta$ $(-\pi \leqslant \theta \leqslant \pi)$, r_c being a "radius" of the extra dimension, and a parameter κ defines a scalar curvature of the five-dimensional space–time. The points (x^μ, y) and $(x^\mu, -y)$ are identified, and the periodicity condition, $(x^\mu, y) = (x_\mu, y + 2\pi r_c)$, is imposed. In Eq. (1) $\eta_{\mu\nu}$ is the Minkowski metric.

We consider the so-called RS1 model [2] which has two 4-dimensional branes with equal and opposite tension located at the point $y = 0$ (called the *TeV brane*, or *visible brane*) and at $y = \pi r_c$ (referred to as the *Planck brane*). All SM fields are constrained to the TeV brane, while the gravity propagates in all five dimensions (bulk).

Since the warp factor $e^{2\kappa|y|}$ is equal to 1 on the TeV brane, four-dimensional coordinates $\{x^\mu\}$ are Galilean and we have a correct determination of the graviton fields on this brane. For a zero mode sector of the effective theory, one obtains a relation between the (reduced) Planck mass and the (reduced) fundamental gravity scale in five dimensions, $\bar{M}_5$:

$$\bar{M}_{\rm Pl}^2 = \frac{\bar{M}_5^3}{\kappa}\left(e^{2\pi\kappa r_c} - 1\right). \tag{2}$$

In a linear approximation, one can parametrize the metric g_{MN} as

$$g_{MN}(z) = \gamma_{MN}(z) + \frac{2}{\bar{M}_5^{3/2}} h_{MN}(z). \tag{3}$$

The invariance of the gravitational action under general coordinate transformation means that the Lagrangian is invariant under gauge transformations of the field $h_{MN}(z)$ (for details, see Refs. [4,5]). If we impose so-called unitary gauge [5], we get

$$h_{\mu 4}(x, y) = 0, \qquad h_{44}(x, y) = \phi(x), \tag{4}$$

where $\phi(x)$ is a massless scalar field which depends on four-dimensional coordinates only. This new degree of freedom called *radion* corresponds to distance oscillations between the branes.

This massless scalar field would lead to such a change of the usual gravitational interaction on the visible brane which is totally excluded by experimental data. However, if the radion acquires the mass of the order of 100 GeV [6], this will not contradict the experimental data, i.e., the radion could be the lightest massive scalar excitation of the RS model.

The field $h_{\mu\nu}(x, y)$ (with a radion contribution singled out) is decomposed into a massless mode $h_{\mu\nu}^{(0)}(x)$ ("classical" graviton) and "Kaluza–Klein" (KK) modes $h_{\mu\nu}^{(n)}(x)$ which describe *massive gravitons*. The mass spectrum of the KK gravitons on the TeV brane is the following:

$$m_n = x_n\kappa, \quad n = 1, 2, \ldots, \tag{5}$$

where x_n are zeros of the Bessel function $J_1(x)$, with $x_n \simeq \pi n$ at large n. The interaction Lagrangian on the visible (TeV) brane looks like

$$\mathcal{L}_{\rm int} = -\frac{1}{\bar{M}_{\rm Pl}} T^{\mu\nu} h_{\mu\nu}^{(0)} - \frac{1}{\Lambda_\pi} T^{\mu\nu} \sum_{n=1}^{\infty} h_{\mu\nu}^{(n)} + \frac{1}{\sqrt{3}\Lambda_\pi} T_\mu^\mu \phi. \tag{6}$$

Here $T^{\mu\nu}$ is the energy–momentum tensor of the matter on the brane, $h_{\mu\nu}^{(n)}$ is the graviton field with the KK-number n and mass m_n (5). The parameter

$$\Lambda_\pi = \left(\frac{\bar{M}_5^3}{\kappa}\right)^{1/2} \tag{7}$$

is a physical scale on the TeV brane. As one can see from (6), the radion field is coupled to the trace of the energy–momentum tensor.

Let us consider two possibilities to satisfy relation (2). One possibility (we will call it "*large curvature option*") is to put

$$\kappa \simeq \bar{M}_5 \sim 1\ \text{TeV}, \tag{8}$$

that corresponds to $\kappa r_c = 11.3$ in Eq. (2). There is a series of KK massive graviton resonances, with the lightest one having a mass of order 1 TeV. As for the radion, it is coupled rather strongly to the SM fields (mainly to gluons) since $\Lambda_\pi \sim 1$ TeV.

Another possibility (we will call it "*small curvature option*" [7,8]) is to take

$$\kappa \ll \bar{M}_5 \sim 1\ \text{TeV}. \tag{9}$$

In such a case, a mass splitting $\Delta m \simeq \pi\kappa$ can be chosen smaller than the energy resolution of LHC experiments. For instance, for $\kappa r_c = 9.7$ we get $\pi\kappa = 50$ MeV, and the mass of the lightest KK excitation

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