Physics Letters B 760 (2016) 502–508

Contents lists available at ScienceDirect

Physics Letters B

www.elsevier.com/locate/physletb

A 750 GeV graviton from holographic composite dark sectors

Adrián Carmona

CERN, Theoretical Physics Department, 1211 Geneva 23, Switzerland

ARTICLE INFO

Article history:
Received 1 April 2016
Received in revised form 7 July 2016
Accepted 15 July 2016
Available online 19 July 2016
Editor: B. Grinstein

ABSTRACT

We show that the 750 GeV di-photon excess can be interpreted as a spin-2 resonance arising from a strongly interacting dark sector featuring some departure from conformality. This spin-2 resonance has negligible couplings to the SM particles, with the exception of the SM gauge bosons which mediate between the two sectors. We have explicitly studied the collider constraints as well as some theoretical bounds in a holographic five dimensional model with a warp factor that deviates from AdS_5. In particular, we have shown that it is not possible to decouple the vector resonances arising from the strong sector while explaining the di-photon anomaly and keeping the five dimensional gravity theory under perturbative control. However, vector resonances with masses around the TeV scale can be present while all experimental constraints are met.

1. Introduction

The discovery of the Higgs boson by the ATLAS and CMS Collaborations at the Large Hadron Collider (LHC) marked the beginning of a new era in high energy physics. Indeed, the finding of the long-sought particle offers us the unique opportunity to start testing the origin of electroweak symmetry breaking (EWSB). This means that we could be closer than ever to understand some extremely important unsolved puzzles in particle physics, like the large hierarchy between the electroweak and the Planck scales, the origin of fermion masses or even what lies behind Dark Matter (DM). The situation has become even more thrilling after the announcement by both ATLAS and CMS Collaborations of a tantalizing hint of a new resonance in di-photon production at masses around ~ 750 GeV [1–3]. Since the exciting news awakened the feverish imagination of theorists, we have witnessed a plethora of papers exploring possible explanations of the reported anomaly. However, for several reasons, the spin-2 possibility has been largely unexplored (see e.g. [4–9]). One of the reasons for this oblivion is that traditional *vanilla* explanations in terms of Kaluza–Klein (KK) gravitons face several problems for such light masses, since they favor either universal couplings to the Standard Model (SM) content or very small $\gamma\gamma$ branching ratios, which are not viable phenomenologically. In addition, unless large localized curvature terms make the spin-2 resonance much lighter than the rest of the KK spectrum, the constraints resulting from electroweak precision tests (EWPT) clearly exclude such scenarios. Moreover, it is known that the presence of such terms can easily turn the radion into a ghost [10,11], questioning the viability of these setups. In this letter we will explore an interesting possibility where the reported 750 GeV resonance may arise from a holographic strongly interacting dark sector. We will show that in models where the strong sector features some deformation of conformality, parametrized in the five dimensional (5D) framework by a modified background, a light graviton can naturally explain the observed anomaly while still fulfilling all other experimental constraints arising from collider searches or EWPT. Moreover, we will demonstrate that all this can be done without introducing a too large gap between the masses of the KK graviton and the rest of the KK spectrum, which will allow to have perturbativity under control in the 5D gravity theory and avoid the emergence of a radion ghost. In addition, we will show that in these models there is a beautiful interplay between the dark sector (possibly explaining part of the observed relic abundance) and the collider phenomenology of the KK vectors. Therefore, measuring the properties of the hypothetical particle, in case its existence is confirmed, will definitively help to answer if it is related to the origin of EWSB or rather with other fundamental puzzles in particle physics, like the origin of DM.

The article is organized as follows: in Section 2 we introduce the original theoretical motivation and the concrete 5D framework where all computations will be performed. This will also serve us to introduce notation and the input parameters of the theory. In Section 3 we will examine in detail the phenomenological consequences of the proposed setups, studying in detail the interplay

E-mail address: adrian.carmona@cern.ch.

http://dx.doi.org/10.1016/j.physletb.2016.07.040
0370-2693/

between EWPT, the different collider searches and role played by the DM candidates. Finally, we conclude in Section 4.

2. Theoretical motivation and setup

Trying to address the hierarchy problem has provided us a better understanding of the SM as well as stimulating theoretical constructions like supersymmetry, composite Higgs models, technicolor or models with warped extra dimensions. However, the multiplication of negative results for such theories has propelled alternative ways of thinking about new physics, disconnecting it e.g. from the electroweak scale. One particular example is the case of DM, where some of these theoretical constructions have been used with the goal of explaining its origin with no deep connection with the electroweak scale, see e.g. [12–17].[1] In the case of models with warped extra dimensions or theirs strongly coupled duals, this more modest and pragmatic approach has some advantages, for typical problems associated with these scenarios are turned into advantages once the hierarchy problem is left unsolved. For instance, in Ref. [16] the most minimal examples where the full SM (including the Higgs boson) is extended with a strongly-interacting composite sector delivering pseudo Nambu–Goldstone bosons (pNGBs) as natural DM candidates were studied. In this letter we are going to explore the possibility that the first spin-2 resonance arising in their holographic constructions can explain the 750 GeV di-photon anomaly.[2] There have been some recent studies on the possibility of interpreting the putative 750 GeV resonance as a KK graviton arising from extra dimensional setups [4–9] but only Refs. [4] and [7] considered the case where the whole SM matter content is UV localized and only gauge bosons are allowed to propagate into the bulk. However, none of them considered the effect of the vector resonances, which were ignored or lifted to $\sim$3–4 TeV without considering the implications on the consistency of the 5D theory or the radion dynamics. Moreover, we will study the more general case where deformations of conformality in the strong sector are allowed, which is parametrized in the 5D theory by a more general warp factor. This will increase the generality of the approach and will improve the agreement with EWPT and collider constraints.

We consider a slice of extra dimension with the following metric

$$ds^2 = e^{-2A(y)}\eta_{\mu\nu}dx^\mu dx^\nu - dy^2, \tag{1}$$

where the warp factor is given by [20–25]

$$A(y) = ky - \frac{1}{\nu^2}\log\left(1-\frac{y}{y_s}\right), \tag{2}$$

and the extra dimension is parametrized by the coordinate $y \in [0, y_1]$, bounded by two fixed points or branes, corresponding to $y = 0$ (UV brane) and $y = y_1$ (IR brane). On the other hand, $y_s > y_1$ represents the position of the singularity responsible for the deformation of conformality, with the AdS_5 case being recovered in the limits $y_s \to \infty$ or $\nu \to \infty$. We show in Fig. 1 the warp factor for different values of ν for $ky_1 = 35$ and $ky_s = 35.1$, as well as for the AdS_5 case. We trade y_s by the curvature radius at the IR brane, given (in units of k) by

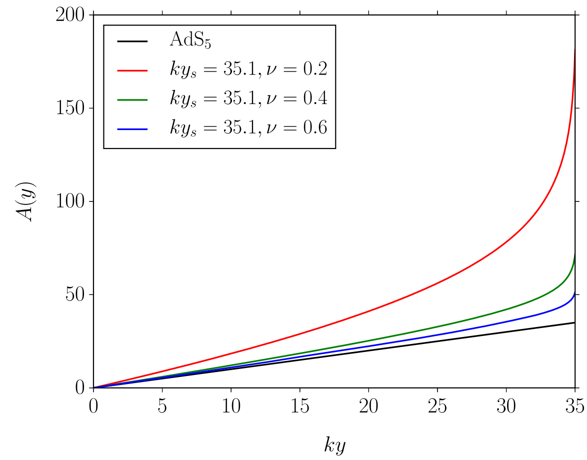

Fig. 1. Warp factor as defined in Eq. (2) for $ky_1 = 35$, $ky_s = 35.1$ and different values of ν. We also show the AdS_5 case for comparison, which corresponds to the limits $\nu \to \infty$ or $ky_s \to \infty$.

$$kL_1 = \frac{\nu^2 k(y_s - y_1)}{\sqrt{1 - 2\nu^2/5 + 2\nu^2 k(y_s-y_1) + \nu^4 k^2 (y_s - y_1)^2}}, \tag{3}$$

where $0.1 \lesssim kL_1 \lesssim 1$. The value of y_1 can be fixed by choosing different values of the UV/IR hierarchy $A(y_1)$. The AdS_5 limit corresponds to $A(y_1) \sim 36$ and $kL_1 \to 1$.

In the transverse-traceless gauge, the spin-2 gravitational excitations are parametrized by the tensor fluctuations of the metric $\eta_{\mu\nu} \to \eta_{\mu\nu} + \kappa_5 h_{\mu\nu}(x,y)$, where $\partial^\mu h_{\mu\nu} = h^\alpha_\alpha = 0$ and $\kappa_5 = 2M_5^{-3/2}$, with M_5 the 5D Planck mass. The graviton KK expansion reads

$$h_{\mu\nu}(x,y) = \sum_n h^{(n)}_{\mu\nu}(x) f^{(n)}_h(y), \tag{4}$$

where $f^{(n)}_h$ satisfy

$$(e^{-4A(y)} f^{(n)\prime}_h(y))' + e^{-2A(y)} m^{(n)2}_h f^{(n)}_h(y) = 0, \tag{5}$$

and

$$\begin{aligned} 0 &= f^{(n)\prime}_h(0) + \kappa_0 k^{-1} m^{(n)2}_h f^{(n)}_h(0) \\ &= e^{-2A(y_1)} f^{(n)\prime}_h(y_1) - \kappa_1 k^{-1} m^{(n)2}_h f^{(n)}_h(y_1), \end{aligned} \tag{6}$$

in presence of possible localized curvature terms [10]. These profiles are normalized

$$\int_0^{y_1} dy\, e^{-2A(y)} f^{(n)2}_h [1 + \delta(y)\frac{\kappa_0}{k} + \delta(y-y_1)\frac{\kappa_1}{k}] = 1, \tag{7}$$

in such a way that

$$\bar{M}^2_{Pl} = M_5^3 \int_0^{y_1} dy e^{-2A(y)} [1 + \delta(y)\frac{\kappa_0}{k} + \delta(y-y_1)\frac{\kappa_1}{k}], \tag{8}$$

where $\bar{M}_{Pl} = 2.4 \times 10^{18}$ GeV is the four-dimensional reduced Planck mass.

In the spirit of the models considered in Ref. [16], we assume that only the SM gauge bosons propagate into the bulk of the extra dimension, with the full SM matter content being localized at the UV brane.[3] In addition, we also assume that the

[1] All these models explore the possibility of having a strongly coupled sector not involved in EWSB. While in [12–14] and [16] the strong sector only talks to the SM via gauge interactions, in [15,17] Yukawa interactions are sometimes allowed. Moreover, Ref. [16] focus on the effective holographic description of such scenarios.

[2] For other examples of spin-2 resonances arising from strongly interacting dark sectors, see e.g. [18,19].

[3] Considering some relatively high new physics scale at the UV brane alleviating the hierarchy problem, would not change the picture, provided the light degrees of freedom remain those of the SM (assuming therefore some moderate fine-tuning).