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The 750 GeV diphoton excess in unified $SU(2)_L \times SU(2)_R \times SU(4)$ models from noncommutative geometry

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We discuss a possible interpretation of the 750 GeV diphoton resonance, recently reported at the LHC, within a class of $SU(2)_L \times SU(2)_R \times SU(4)$ models with gauge coupling unification. The unification is imposed by the underlying non-commutative geometry (NCG), which in these models is extended to a left-right symmetric completion of the Standard Model (SM). Within such *unified* $SU(2)_L \times SU(2)_R \times SU(4)$ models the Higgs content is restrictively determined from the underlying NCG, instead of being arbitrarily selected. We show that the observed cross sections involving the 750 GeV diphoton resonance could be realized through a SM singlet scalar field accompanied by colored scalars, present in these unified models. In view of this result we discuss the underlying rigidity of these models in the NCG framework and the wider implications of the NCG approach for physics beyond the SM.

Keywords: Non-commutative geometry; left-right symmetric model; Pati-Salam model, colored scalars, LHC

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1. Introduction

After the discovery of the Higgs boson, the obvious burning question of particle physics is: what lies beyond the completed physics of the Standard Model (SM)? For many years, theoretical extensions of the SM have been driven by the hard lessons learned (and perhaps prejudices acquired) in the context of effective field theory, the underlying language of the SM. In these discussions, which include supersymmetry, technicolor, and extra dimensions, among many others, the theoretical motivations were rooted in deep questions such as the hierarchy problem, or the idea of grand unification (GUT).^a More recently, growing attention has been devoted to

^aFor a review see, for example, Ref. 1.

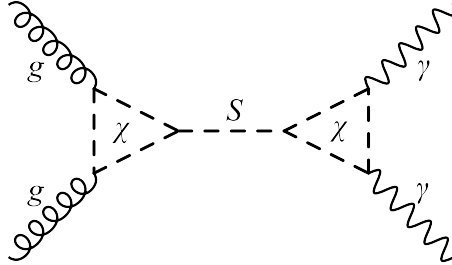
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Fig. 1. The Feynman diagram of the production and decay of the SM-singlet scalar S at the LHC through colored-scalar χ in the loop.

the underlying non-commutative geometry (NCG) of the Standard Model,^b with implications for its natural left-right symmetric completion, as discussed in Refs. 4 and 5. In the NCG framework, the SM itself harbors a GUT-like structure, and its natural completion appears to be a GUT-like *unified* $G_{224} = SU(2)_L \times SU(2)_R \times SU(4)$ model. The question is: are there any hints for this unified G_{224} NCG framework in the observed world, as opposed to the canonical non-restricted versions?^{1, 6–10c}

Recently, ATLAS¹⁴ and CMS¹⁵ have both reported a resonance in the diphoton channel with an invariant mass around 750 GeV. The local significances were respectively 3.6σ and 2.6σ , assuming a narrow width resonance. These signals may be the first hint associated with the long-anticipated physics beyond the SM. The 95% CL cross section upper limit around 750 GeV set by ATLAS (CMS) is roughly 10 ± 2.8 fb (6.5 ± 3.5 fb) using 3.2 fb⁻¹ (2.6 fb⁻¹) of data at $\sqrt{s} = 13$ TeV, assuming the resonance is a scalar produced through gluon-gluon fusion. When the width of the resonance is allowed to vary, a maximum local significance of 3.9σ is attained by ATLAS at a width of 45 GeV. On the other hand, the local significance attains its maximum for a narrow width resonance in the CMS results. Therefore, at this stage, given these preliminary analyses, it is difficult to infer conclusively whether the width of the resonance is wide or narrow.¹⁶

In this letter, we discuss a possible identification of this resonance with SM-singlet scalars in the NCG motivated unified G_{224} models.^{4, 5} A plausible and economical way to realize the LHC diphoton signal in the unified G_{224} context is to couple this SM-singlet scalar to gluons and photons via loops of colored scalars, as recently discussed in Ref. 17 in the context of $SO(10)$ GUT, cf. Fig. 1.^d The NCG models we consider have either an $SU(2)_R$ triplet $\Delta_R(1, 3, 10)$, or an $SU(2)_R$ doublet $\tilde{\Delta}_R(1, 2, 4)$ in their scalar content, where the three numbers refer to the dimensions of the $G_{224} = SU(2)_L \times SU(2)_R \times SU(4)_C$ irreducible representations.

^bFor recent reviews see Refs. 2, 3.

^cSee Refs. 11, 12, 13 for recent discussions.

^dDasgupta et al. in Ref. 18 have shown that coupling the SM-singlet scalar to quarks and photons via mixing with the SM Higgs boson would lead to too small a cross section.

The SM-singlet scalar \mathcal{S} , which we identify with the 750 GeV resonance, is assumed to be the excitation of the electrically neutral component Δ_{R1}^0 of $\Delta_R(1, 3, 10)$, or that of $\tilde{\Delta}_R(1, 2, 4)$ (denoted as $\tilde{\Delta}_{R1}^0$), depending on the model considered. Δ_{R1}^0 (or $\tilde{\Delta}_{R1}^0$) is also the field that breaks the gauge symmetry of the G_{224} model to that of the SM, by acquiring a vacuum expectation value (VEV) at the scale M_C where G_{224} breaks to $G_{213} = SU(2)_L \times U(1)_Y \times SU(3)_C$ of the SM. A color-triplet components of $\Delta_R(1, 3, 10)$ (or $\tilde{\Delta}_R(1, 2, 4)$) is assumed to survive down to low energies (TeV-scale) to take on the role of the χ -field in Fig. 1. This is but one way that one could embed the 750 GeV diphoton resonance into the NCG G_{224} framework, and we use this as a demonstrative example.

While this identification itself is fairly straightforward, and it can already be inferred from the similar $SO(10)$ analysis of Ref. 17 that the cross section and width can be made to come out in the right ballpark, the question is whether the assumed symmetry breaking and scalar survival scenario can actually be realized in the NCG G_{224} models, given the gauge-coupling-unification requirement and restricted scalar content which limits our ability to adjust the renormalization group running of those couplings. Indeed, we have demonstrated in Ref. 11 that realizing a 2 TeV W_R , which had been suggested by the LHC data,^{19–24} in the same NCG models was highly non-trivial due to the unification requirement applying conflicting pressure on the symmetry breaking scales. Thus, we subject our scenarios to renormalization group equation (RGE) analyses to check their feasibilities.

The main message of this letter is that even though the 750 GeV diphoton resonance can be accommodated within the NCG motivated unified G_{224} models, the price one has to pay is a certain amount of fine tuning in the sector involving the necessary colored scalars. This is somewhat similar to the main message of Ref. 11, and points to the underlying rigidity of the NCG framework. However, this conclusion is based on effective-field-theory reasoning, which could fail in the NCG framework due to the possible mixing between the short-distance and long-distance physics as discussed in our previous work.^{11–13}

This letter is organized as follows. In section 2, we present the list of the NCG based unified G_{224} models that are analyzed, and discuss how the 750 GeV diphoton resonance could be explained within their framework. In section 3, we address the question of whether the unification of gauge couplings can be achieved naturally in those models. We conclude in section 4 with an outlook on the rigid phenomenological aspects of the NCG framework. In the process, we follow the technology discussed in our previous paper¹¹ to which we refer the reader for further technical details.

2. Diphoton resonance in NCG based unified G_{224} models

In this section, we list the three unified G_{224} models proposed by Chamseddine, Connes, and van Suijlekom in Refs. 4 and 5, and specify how we fit the diphoton resonance into their particle content. These models emerge from an underlying NCG,

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Table 1. The scalar content of the three NCG based unified G_{224} models proposed by Chamseddine, Connes, and van Suijlekom in Refs. 4 and 5, compared to the scalar content of the $SO(10)$ based G_{224} model, discussed in Ref. 16, below its unification scale where the $SO(10)$ symmetry is broken to G_{224} .

Model	Symmetry	Higgs Content
A	G_{224}	$\phi(2, 2, 1), \tilde{\Delta}_R(1, 2, 4), \Sigma(1, 1, 15)$
B	G_{224}	$\phi(2, 2, 1), H(1, 1, 6), \Delta_R(1, 3, 10), \tilde{\Sigma}(2, 2, 15)$
C	G_{224D}	$\phi(2, 2, 1), H(1, 1, 6) \times 2, \Delta_R(1, 3, 10), \Delta_L(3, 1, 10), \tilde{\Sigma}(2, 2, 15)$
$SO(10)$	G_{224}	$\phi(2, 2, 1), \Delta_R(1, 3, 10), \Sigma(1, 1, 15)$

which is an extension of the NCG of the SM to that of left-right symmetric models. The three versions differ in the scalar sector content, and the unbroken symmetry structure as listed in Table 1. We use the following notation for the symmetries:

$$\begin{aligned}
G_{224D} &= SU(2)_L \otimes SU(2)_R \otimes SU(4)_C \otimes D , \\
G_{224} &= SU(2)_L \otimes SU(2)_R \otimes SU(4)_C , \\
G_{213} &= SU(2)_L \otimes U(1)_Y \otimes SU(3)_C , \\
G_{13} &= U(1)_Q \otimes SU(3)_C ,
\end{aligned} \tag{1}$$

where D in G_{224D} refers to the left-right symmetry, a Z_2 symmetry which keeps the left and the right sectors equivalent. The last row of Table 1 lists the scalar content of an $SO(10)$ based G_{224} model studied in Ref. 17, below its unification scale where the $SO(10)$ had broken to G_{224} . The scalars $\phi(2, 2, 1)$, $\Delta_R(1, 3, 10)$, $\Sigma(1, 1, 15)$ are respectively obtained from the $SO(10)$ multiplets **10** (or **120**), **126**, and **210**. The **210** also includes a $(1, 1, 1)$ representation, whose VEV breaks $SO(10)$ down to G_{224} .²⁵

As in our previous paper¹¹ we will not attempt to review the NCG foundations of these models or to justify their derivation, but simply look at their consequences from a purely phenomenological viewpoint in the light of the possible 750 GeV diphoton resonance. The distinguishing feature of NCG motivated versions of the SM^{2,3} as well as its G_{224} completion discussed here is that they come with GUT-like coupling unification conditions, due to the underlying spectral action having only one overall coupling. This is not the case for the canonical G_{224} constructions found in the literature.^{1,6-9}

The decompositions of the various scalar fields, which appear in Table 1, into irreducible representations of the subgroups as the symmetry breaks from G_{224} (or G_{224D}) to G_{2213} and then to G_{213} are shown in Table 2. In model A, we assume that G_{224} is broken directly to G_{213} by $\tilde{\Delta}_{R1}^0(1, 0, 1)$ acquiring a VEV, and \mathcal{S} is identified with the excitation of $\tilde{\Delta}_{R1}^0$. In models B and C, we assume that G_{224}/G_{224D} is broken directly to G_{213} by $\Delta_{R1}^0(1, 0, 1)$ acquiring a VEV, while \mathcal{S} is identified with

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the excitation of Δ_{R1}^0 . In all three models, the colored field $\Delta_{R3}^{-2/3}(1, -4/3, 3)$, which is contained in the decompositions of both $\tilde{\Delta}_R(1, 2, 4)$ and $\Delta_R(1, 3, 10)$, is assumed to survive below the symmetry breaking scale.

Table 2. The decomposition of various G_{224} representations into those of G_{2213} and G_{213} (SM).

G_{224}	G_{2213}	G_{213}
$\phi(2, 2, 1)$	$\phi(2, 2, 0, 1)$	$\phi_2(2, 1, 1), \phi'_2(2, -1, 1)$
$\tilde{\Delta}_R(1, 2, 4)$	$\tilde{\Delta}_{R1}(1, 2, 1, 1)$	$\tilde{\Delta}_{R1}^0(1, 0, 1), \tilde{\Delta}_{R1}^+(1, 2, 1)$
	$\tilde{\Delta}_{R3}\left(1, 2, -\frac{1}{3}, 3\right)$	$\tilde{\Delta}_{R3}^{1/3}\left(1, \frac{2}{3}, 3\right), \tilde{\Delta}_{R3}^{-2/3}\left(1, -\frac{4}{3}, 3\right)$
$\Delta_R(1, 3, 10)$	$\Delta_{R1}(1, 3, 2, 1)$	$\Delta_{R1}^0(1, 0, 1), \Delta_{R1}^+(1, 2, 1), \Delta_{R1}^{++}(1, 4, 1)$
	$\Delta_{R3}\left(1, 3, \frac{2}{3}, 3\right)$	$\Delta_{R3}^{+4/3}\left(1, \frac{8}{3}, 3\right), \Delta_{R3}^{+1/3}\left(1, \frac{2}{3}, 3\right), \Delta_{R3}^{-2/3}\left(1, -\frac{4}{3}, 3\right)$
	$\Delta_{R6}\left(1, 3, -\frac{2}{3}, 6\right)$	$\Delta_{R6}^{+2/3}\left(1, \frac{4}{3}, 6\right), \Delta_{R6}^{-1/3}\left(1, -\frac{2}{3}, 6\right), \Delta_{R6}^{-4/3}\left(1, -\frac{8}{3}, 6\right)$
$\Delta_L(3, 1, 10)$	$\Delta_{L1}(3, 1, 2, 1)$	$\Delta_{L1}(3, 2, 1)$
	$\Delta_{L3}\left(3, 1, \frac{2}{3}, 3\right)$	$\Delta_{L3}\left(3, \frac{2}{3}, 3\right)$
	$\Delta_{L6}\left(3, 1, -\frac{2}{3}, 6\right)$	$\Delta_{L6}\left(3, -\frac{2}{3}, 6\right)$
$H(1, 1, 6)$	$H_3\left(1, 1, \frac{2}{3}, 3\right)$	$H_3^{1/3}\left(1, \frac{2}{3}, 3\right)$
	$H_{\bar{3}}\left(1, 1, -\frac{2}{3}, \bar{3}\right)$	$H_{\bar{3}}^{-1/3}\left(1, -\frac{2}{3}, \bar{3}\right)$
$\Sigma(1, 1, 15)$	$\Sigma_1(1, 1, 0, 1)$	$\Sigma_1^0(1, 0, 1)$
	$\Sigma_3\left(1, 1, -\frac{4}{3}, 3\right)$	$\Sigma_3^{-2/3}\left(1, -\frac{4}{3}, 3\right)$
	$\Sigma_{\bar{3}}\left(1, 1, \frac{4}{3}, \bar{3}\right)$	$\Sigma_{\bar{3}}^{2/3}\left(1, \frac{4}{3}, \bar{3}\right)$
	$\Sigma_8(1, 1, 0, 8)$	$\Sigma_8^0(1, 0, 8)$
$\tilde{\Sigma}(2, 2, 15)$	$\tilde{\Sigma}_1(2, 2, 0, 1)$	$\tilde{\Sigma}_1(2, 1, 1), \tilde{\Sigma}'_1(2, -1, 1)$
	$\tilde{\Sigma}_3\left(2, 2, -\frac{4}{3}, 3\right)$	$\tilde{\Sigma}_3\left(2, -\frac{7}{3}, 3\right), \tilde{\Sigma}'_3\left(2, -\frac{1}{3}, 3\right)$
	$\tilde{\Sigma}_{\bar{3}}\left(2, 2, \frac{4}{3}, \bar{3}\right)$	$\tilde{\Sigma}_{\bar{3}}\left(2, \frac{7}{3}, \bar{3}\right), \tilde{\Sigma}'_{\bar{3}}\left(2, \frac{1}{3}, \bar{3}\right)$
	$\tilde{\Sigma}_8(2, 2, 0, 8)$	$\tilde{\Sigma}_8(2, 1, 8), \tilde{\Sigma}'_8(2, -1, 8)$

The advantage of this choice of the surviving colored scalar is that it exists in all three models, and that it is similar to the one considered in the $SO(10)$ context in Ref. 17, where the reproducibility of the recently reported LHC signal has been demonstrated with such a new degree of freedom. The other colored components of $\tilde{\Delta}_R(1, 2, 4)$ and $\Delta_R(1, 3, 10)$ could also serve this end. Single step breaking from G_{224} to G_{213} is assumed for the sake of simplicity,^e and also due to our experience in Ref. 11 telling us that introducing multi-step breaking does not necessarily facilitate the grafting of the NCG models to the SM at low energies.

In the $SO(10)$ model of Ref. 17, the 750 GeV resonance \mathcal{S} was identified with the excitation of the charge neutral component Δ_{R3}^0 of $\Delta_R(1, 3, 10)$, which acquires a VEV breaking G_{2213} down to G_{213} at $M_R = 5$ TeV, and only one of the colored components, $\chi = \Delta_{R3}^{-2/3}(1, -4/3, 3)$, was assumed to survive below this breaking. This is the exact same identification as in models B and C, except the assumed symmetry breaking pattern is different. Since \mathcal{S} is a singlet under the SM gauge group G_{213} , it cannot directly couple to gluons or photons. The coupling is induced by χ -loops as shown in Fig. 1. Assuming a coupling between \mathcal{S} and χ of the form

$$\kappa M_R \mathcal{S} \chi^\dagger \chi, \quad M_R = 5 \text{ TeV}, \quad (2)$$

where κ is a dimensionless parameter, and $M_\chi > M_S/2$ so that \mathcal{S} does not decay into a χ pair, it has been shown in Ref. 17 that the LHC signal can be reproduced for a wide range of (κ, M_χ) values around $\kappa = O(1)$ and $M_\chi = O(1 \text{ TeV})$. Thus, without repeating the analysis we conclude that our NCG models can also reproduce the LHC signal provided a similar coupling exists between \mathcal{S} and χ , and the assumed particle content allows the required unification of gauge couplings at a high scale.

Several comments are in order. The $\Delta_R(1, 3, 10)$ scalar is associated with a rich phenomenology as discussed by Mohapatra and Marshak in Ref. 10, including the generation of Majorana neutrino mass and neutron-anti-neutron oscillations. These depend on the Yukawa couplings of the $\Delta_R(1, 3, 10)$ to the fermions, and the quartic coupling of the $\Delta_R(1, 3, 10)$ to itself. In the NCG approach, the Dirac operator, which includes the Yukawa couplings, is the input from which the entire model is constructed. The scalar content of the model as well as their quartic couplings are derived from the Dirac operator.^f Therefore, the NCG approach can, in principle, make predictions in regards to neutron-anti-neutron oscillations. However, it is necessary to check the viability of the model before performing such detailed analyses, so this will not be discussed further in this paper.

3. Unification of the couplings

As discussed in the introduction, the unification of couplings in the NCG based G_{224} models imposes non-trivial requirements on the symmetry breaking scales,

^eIn models B and C, the breaking sequence $G_{224} \rightarrow G_{2213} \rightarrow G_{213}$ considered in Ref. 11 requires scalar composites acquiring a VEV in the intermediate steps.

^fSee appendix of Ref. 4.

given that the scalar content of each model is restricted and cannot be changed at will. In this section, we discuss whether the unification of the couplings can be achieved in the NCG based G_{224} models with the assumed particle content and scalar survival assumptions. In contrast to our work in Ref. 11, we assume direct breaking of G_{224} to G_{213} at a single scale M_C , between the unification scale M_U and the electroweak symmetry breaking (EWSB) scale M_Z . Between the scales M_C and M_Z , in addition to the usual SM particle content we have the $\chi = \Delta_{R3}^{-2/3}(1, -4/3, 3)$ field contributing to the RGE, which we assume is the only colored scalar to survive below M_C , and possess a mass of around a TeV. The 750 GeV scalar \mathcal{S} is an SM singlet and consequently does not contribute to the RG running of the SM gauge couplings.

3.1. Boundary and Matching Conditions

The symmetry breaking chain of the model considered in this letter has been discussed in detail in our previous papers.^{11,26} The ordering of the breaking scales must be strictly maintained in the computations, *i.e.*

$$M_U \geq M_C \geq M_Z . \quad (3)$$

We label the energy intervals in between symmetry breaking scales $[M_Z, M_C]$ and $[M_C, M_U]$ with Roman numerals as

$$\begin{aligned} \text{I} &: [M_Z, M_C], \quad G_{213} \text{ (SM)} , \\ \text{II} &: [M_C, M_U], \quad G_{224} \text{ or } G_{224D} . \end{aligned} \quad (4)$$

The boundary/matching conditions we impose on the couplings at the symmetry breaking scales are:

$$\begin{aligned} M_U &: g_L(M_U) = g_R(M_U) = g_4(M_U) , \\ M_C &: \sqrt{\frac{2}{3}} g_{BL}(M_C) = g_3(M_C) = g_4(M_C) , \quad g_2(M_C) = g_L(M_C) , \\ &\quad \frac{1}{g_1^2(M_C)} = \frac{1}{g_R^2(M_C)} + \frac{2}{3} \frac{1}{g_4^2(M_C)} , \\ M_Z &: \frac{1}{e^2(M_Z)} = \frac{1}{g_1^2(M_Z)} + \frac{1}{g_2^2(M_Z)} . \end{aligned} \quad (5)$$

The low energy data which we will use as boundary conditions to the RG running are^{27,28}

$$\alpha(M_Z) = 1/127.9 , \quad \alpha_s(M_Z) = 0.118 , \quad \sin^2 \theta_W(M_Z) = 0.2312 , \quad (6)$$

at $M_Z = 91.1876$ GeV, which translates to

$$g_1(M_Z) = 0.36 , \quad g_2(M_Z) = 0.65 , \quad g_3(M_Z) = 1.22 . \quad (7)$$

Note that the coupling constants are all required to remain in the perturbative regime during the evolution from M_U down to M_Z .

3.2. One-loop renormalization group running

For a given particle content; the gauge couplings, in an energy interval $[M_A, M_B]$, are evolved according to the 1-loop RG relation

$$\frac{1}{g_i^2(M_A)} - \frac{1}{g_i^2(M_B)} = \frac{a_i}{8\pi^2} \ln \frac{M_B}{M_A}, \quad (8)$$

where the RG coefficients a_i are given by^{29,30}

$$\begin{aligned} a_i = & -\frac{11}{3}C_2(G_i) + \frac{2}{3} \sum_{R_f} T_i(R_f) \cdot d_1(R_f) \cdots d_n(R_f) \\ & + \frac{\eta}{3} \sum_{R_s} T_i(R_s) \cdot d_1(R_s) \cdots d_n(R_s). \end{aligned} \quad (9)$$

The summation in Eq. (9) is over irreducible chiral representations of fermions (R_f) in the second term and those of scalars (R_s) in the third. The coefficient η is either 1 or 1/2, depending on whether the corresponding representation is complex or real, respectively. $C_2(G_i)$ is the quadratic Casimir for the adjoint representation of the group G_i , and T_i is the Dynkin index of each representation. For $U(1)$ group, $C_2(G) = 0$ and

$$\sum_{f,s} T = \sum_{f,s} \left(\frac{Y}{2} \right)^2, \quad (10)$$

where $Y/2$ is the $U(1)$ charge, the factor of 1/2 coming from the traditional normalizations of the hypercharge and $B - L$ charges.

The RG coefficients, a_i , differ depending on the particle content in each energy interval, changing every time symmetry breaking occurs. We will distinguish the a_i 's in different intervals with the corresponding roman numeral superscript, cf. Eq. (4). Together with the matching and boundary conditions of Eqs. (5), (6), (7), 1-loop RG running leads to the following conditions on the symmetry breaking scales M_U and M_C :

$$\begin{aligned} 2\pi \left[\frac{3 - 8 \sin^2 \theta_W(M_Z)}{\alpha(M_Z)} \right] &= (3a_1 - 5a_2)^I \ln \frac{M_C}{M_Z} + (-5a_L + 3a_R + 2a_4)^{II} \ln \frac{M_U}{M_C}, \\ 2\pi \left[\frac{3}{\alpha(M_Z)} - \frac{8}{\alpha_s(M_Z)} \right] &= (3a_1 + 3a_2 - 8a_3)^I \ln \frac{M_C}{M_Z} + (3a_L + 3a_R - 6a_4)^{II} \ln \frac{M_U}{M_C}. \end{aligned} \quad (11)$$

The unified coupling α_U at scale M_U can then be obtained from

$$\frac{2\pi}{\alpha_U} = \frac{2\pi}{\alpha_s(M_Z)} - \left(a_4^{II} \ln \frac{M_U}{M_C} + a_3^I \ln \frac{M_C}{M_Z} \right). \quad (12)$$

Thus, once the RG coefficients in each interval are specified, the scales M_U and M_C , and the value of α_U will be uniquely determined. For the computations to be meaningful, however, M_U must stay below the Planck scale, and α_U must be in the perturbative regime.

3.3. Results

The particle content and the RG coefficients for the three models in the two energy intervals are listed in Tables. 3, 4, and 5. As stated above, though \mathcal{S} survives in the energy interval I, being an SM singlet, it does not contribute to the RG coefficients. The values of M_U , M_C , and α_U obtained using the formalism above are listed in Table. 6. The running of the gauge couplings for the three models are shown in Figure 2.

We see that for all three models, M_U is below the Planck scale and α_U is perturbative, as are all the gauge couplings during their course of running. The value of the symmetry breaking scale M_C is high in the $10^{10\sim 13}\text{GeV}$ range, suggesting that providing \mathcal{S} and $\chi = \Delta_{R3}^{-2/3}(1, -4/3, 3)$ with TeV scale masses, and the TeV scale coupling $\kappa M_R \mathcal{S} \chi^\dagger \chi$ between them would involve fine tuning.

Table 3. The Higgs content and the RG coefficients in the energy intervals for model A.

Interval	Higgs content	RG coefficients
II	$\phi(2, 2, 1), \tilde{\Delta}_R(1, 2, 4), \Sigma(1, 1, 15)$	$(a_L, a_R, a_4)^{\text{II}} = \left(-3, \frac{-7}{3}, \frac{-29}{3}\right)$
I	$\phi_2(2, 1, 1), \mathcal{S}(1, 0, 1), \tilde{\Delta}_{R3}^{-2/3}\left(1, \frac{-4}{3}, 3\right)$	$(a_1, a_2, a_3)^{\text{I}} = \left(\frac{131}{18}, \frac{-19}{6}, \frac{-41}{6}\right)$

Table 4. The Higgs content and the RG coefficients in the energy intervals for model B.

Interval	Higgs content	RG coefficients
II	$\phi(2, 2, 1), H(1, 1, 6), \Delta_R(1, 3, 10),$ $\tilde{\Sigma}(2, 2, 15)$	$(a_L, a_R, a_4)^{\text{II}} = \left(2, \frac{26}{3}, -2\right)$
I	$\phi_2(2, 1, 1), \mathcal{S}(1, 0, 1), \Delta_{R3}^{-2/3}\left(1, \frac{-4}{3}, 3\right)$	$(a_1, a_2, a_3)^{\text{I}} = \left(\frac{131}{18}, \frac{-19}{6}, \frac{-41}{6}\right)$

Table 5. The Higgs content and the RG coefficients in the energy intervals for model C.

Interval	Higgs content	RG coefficients
II	$\phi(2, 2, 1), H(1, 1, 6) \times 2, \tilde{\Sigma}(2, 2, 15)$ $\Delta_R(1, 3, 10), \Delta_L(3, 1, 10)$	$(a_L, a_R, a_4)^{\text{II}} = \left(\frac{26}{3}, \frac{26}{3}, \frac{4}{3}\right)$
I	$\phi_2(2, 1, 1), \mathcal{S}(1, 0, 1), \Delta_{R3}^{-2/3}\left(1, \frac{-4}{3}, 3\right)$	$(a_1, a_2, a_3)^{\text{I}} = \left(\frac{131}{18}, \frac{-19}{6}, \frac{-41}{6}\right)$

Table 6. The predictions of Models A, B, and C.

Model	A	B	C
Unbroken Symmetry	G_{224}	G_{224}	G_{224D}
$\log_{10}(M_U/\text{GeV})$	15.7	17.1	15.6
$\log_{10}(M_C/\text{GeV})$	13.3	10.5	13.4
α_U^{-1}	45.4	34.7	36.2

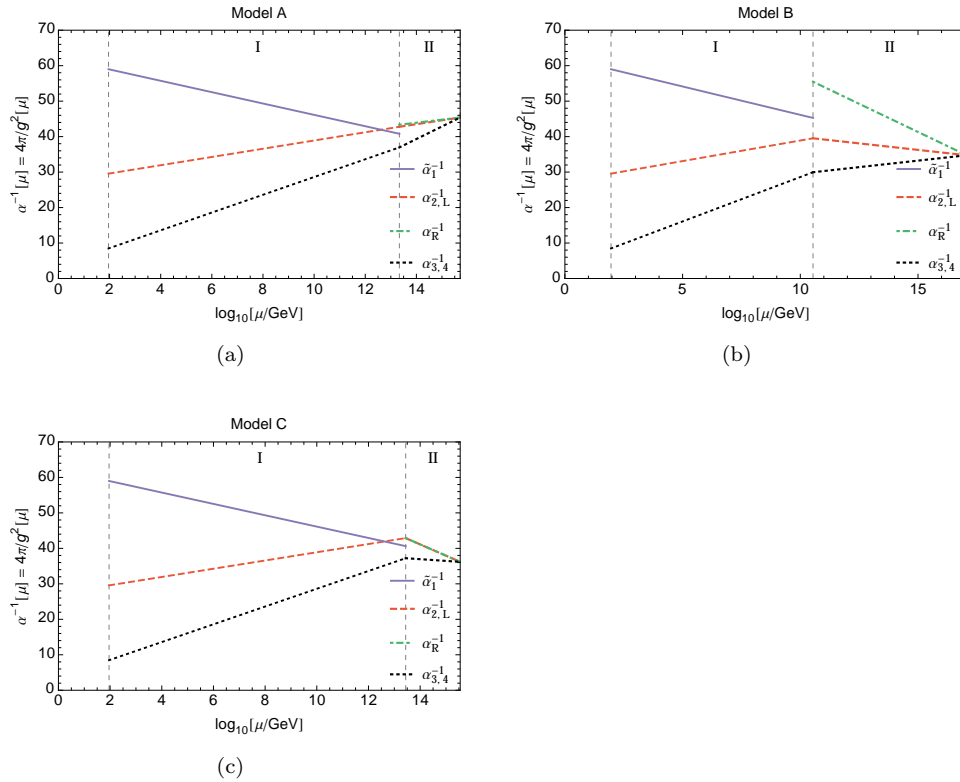


Fig. 2. Running of the gauge couplings for models A, B, and C. The vertical dotted lines from left to right correspond to the symmetry breaking scales M_Z and M_C , which also indicate the beginning of the energy intervals I and II, respectively. For α_1^{-1} , we plot the redefined quantity $\tilde{\alpha}_1^{-1} \equiv \frac{3}{5}\alpha_1^{-1}$. Note that in (a), in the interval II, α_L^{-1} and α_R^{-1} evolve very closely but not identically.

4. Discussion

In this letter, we have discussed a possible interpretation of the 750 GeV diphoton resonance in the framework of unified G_{224} models derived in the context of a left-

right symmetric extension of non-commutative geometry (NCG) of the Standard Model (SM). Our framework is a grand unified version of G_{224} models, within which the corresponding Higgs content is restrictively determined (or uniquely determined for each model) from the underlying non-commutative geometry. This should be contrasted to the regular G_{224} models, discussed in the literature, in which the corresponding Higgs context is arbitrarily selected.

In this note, we have argued that the observed cross sections involving the 750 GeV diphoton resonance could be realized through a SM singlet scalar field and colored scalars in the NCG of unified G_{224} models. However the color scalars are light and thus fine tuned from the usual effective field theory point of view. This indicates a certain rigidity of the NCG approach to the Standard Model and its natural completion in the context of the unified G_{224} models. As already emphasized, this conclusion is based on the effective field theory reasoning, which might fail in the NCG framework due to the possible mixing between the short-distance and long-distance physics as we have discussed in our previous papers Ref. 11, as well as Refs. 12, 13. In this paper we have discussed three different scenarios and their implications for the physics beyond the Standard Model. We have concentrated on the purely phenomenological aspects of the NCG unified G_{224} models without relying on their deep mathematical structure or various novel physics aspects that go beyond the effective field theory framework.

We believe that the discussion presented in this note gives extra evidence to the underlying phenomenological rigidity of the NCG approach towards understanding of the origins of the Standard Model and the physics beyond the Standard Model. However, this phenomenological rigidity might be the price one has to pay for the non-commutative nature of the approach, and it might be indicative of a possibly exciting relation to the non-particle sector of high energy physics, that is to be found in the context of the underlying quantum structure of space and time.

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