Phenomenology of the simple 3-3-1 model with inert scalars	Hiện tượng luận về mô hình 3-3-1 đơn giản với các vô hướng trơ

The simple 3-3-1 model that contains the minimal lepton and minimal scalar content is detailedly studied. The impact of the inert scalars, which provides dark matter candidates, on the model is discussed. All the interactions of the model are derived, and the standard model ones are identified. We make a search for the new particles including the inert ones which lead to the observed diphoton excess, rare Bs ^ ^+^- decay, and Bs-Bs mixing as well as constraining the standard model Higgs like particle at the LHC.

I. INTRODUCTION

One of the promising extensions of the standard model is the model based on the SU(3)C® SU (3) L ® U(1)x (3-3-1) gauge symmetry [1, 2], such that it can explain the neutrino masses [3] , dark matter [4, 5], fermion generation number [6], oddly heavy top quark [7], flavor physics [8], electric charge quantization [9], and strong CP conservation [10]. There are numerous 3-3-1 versions proposed so far, but they mainly differ due to the lepton and scalar contents. Given a favor of the version with the minimal lepton and scalar content, the suitable one is the so-called simple 3-3-1 model. This model was firstly introduced in [5] in order to resolve the problems associated with the reduced 3-3-1 model [11]. Additionally, the dark mater can be naturally implemented in this new proposal, as also stated in [5].

It was shown in [12] that the considering model encounters a serious discrepancy be¬tween the FCNCs and p-parameter bounds on the new physics scale, which is

Trong bài báo này, chúng tôi nghiên cứu chi tiết mô hình 3-3-1 đơn giản chứa thành phần lepton cực tiểu và thành phần vô hướng cực tiểu. Bài báo tập trung phân tích tác động của các vô hướng trơ (tạo các ứng viên vật chất tối) đến mô hình. Chúng ta sẽ rút ra tất cả các tương tác của mô hình, và xác định các tương tác mô hình chuẩn. Chúng tôi tìm kiếm những hạt mới bao gồm các hạt trơ dẫn đến hiện tượng dư thừa diphoton, phân rã hiếm….., và sự pha trộn Bs-Bs cũng như áp đặt các điều kiện đối với hạt dạng Higg mô hình tiêu chuẩn tại LHC.

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experimen¬tally unacceptable. This can be understood as follows: The FCNCs constrain the 3-3-1 breaking scale to be w > 3.6 TeV. With this limit, the new physics contribution due to the normal sector of the simple 3-3-1 model to the p-parameter is negligible. This im¬plies that the inert scalars are necessarily included as they are, which provides dark mat¬ter candidates. The presence of the inert scalars can solve the experimental p-parameter, 0.00016 < (Ap)new —physics < 0.00064, since one of the inert doublets contained in the inert multiplet 0 = r(, x' or a can be used to break the vector part of weak SU(2) and lead to a positive contribution as (Ap)inert—doubiet = Am2, where

Am2 = m? + m2 - ln mi, (1)

denotes the mass splitting between the inert doublet components [13]. Compared to the bounds, it yields (22.5 GeV)2 < Am2 < (45 GeV)2, in good agreement with the dark matter constraints where m? and m2 can range from the weak scale to TeV scale [5]. The above observation makes the simple 3-3-1 model realistic (i.e., alive) as well as showing the importance of the inert scalars, besides the other strong connections between the two sectors as presented in [5]. Motivated by this fact, in the current work, the normal sector of the simple 3-3-1 model is in detail investigated, taking into account the effect of the inert sector too. It is noted that the inert sector was explicitly obtained in [5], and in this work, it would be appropriately used whenever it contributes to the normal sector. First of all, we give a brief review of the model. All the interactions in the normal sector will be calculated. The interactions between the

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normal and inert sectors were available, which could be found in [5]. Next, we consider the standard model Higgs like particle signature at the LHC when additionally including the effects of the new particles. We also examine the decay anomaly Bs ^ ^+^— and Bs-Bs mixing, which constrain Z' boson. The searches for the new scalars H0, H±, 0 and new gauge bosons Z', X±, Yare lastly discussed.

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The rest of this work is organized as follows. In Sec. II, the necessary features of the model are given. In Sec. III, we calculate relevant interactions. Section IV is devoted to constraining the standard model Higgs like particle as well as the searches for the new physics. Finally, we summarize our results and make conclusions in Sec. V.

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II. THE MODEL

The gauge symmetry of the model is given by SU(3)C ® SU(3)L ® U(1)x, where the first factor is the ordinary QCD group, while the last two are a nontrivial extension of the electroweak groups. The standard model fermion doublets will be enlarged to SU(3)L triplets/antitriplets, whereas the standard model fermion singlets, possibly including right¬handed neutrinos, are retained as corresponding SU(3)L singlets or included to complete the fermion triplets/antitriplets. The latter case may be valid for leptons, but it does not apply for quarks because of the commutation among SU(3)C, SU(3)L, and the spacetime symmetry; therefore, the introduction of exotic quarks for the quark

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triplets/antitriplets is necessary. Such arrangement hints the fermion generation number equals the fundamental color number (i.e., 3), when the anomaly cancelation and QCD asymptotic freedom are imposed. The latter case implies the quantization of electric charge, when the anomaly cancelation and mass generation are applied. In the following, we are interested in the model that its lepton sector uses only those of the standard model, no new lepton is required, and of course the electric charge is embedded in the gauge symmetry as $Q = T3 — \sqrt{3}T8 + X$, where T (i = 1, 2, 3,.., 8) and X are the generators of SU (3)L and U (1)x , respectively. Furthermore, the SU(3)C generators will be denoted as t*.

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The fermion content, which is anomaly free, is given by

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where a = 1, 2, 3 and a =1, 2 are generation indices. The quantum numbers in the paren¬theses (NC, NL, X) define corresponding representations under the (SU(3)C, SU(3)L, U(1)X) groups, respectively. The superscript c indicates the charge conjugation, (eR)c — CeR = (ec)L, as usual. The new quarks Ja have exotic electric charges such as Q(Ja) = —4/3 and Q(J3) = 5/3. The third generation of quarks has been arranged differently from the first two, in order to have a well-defined new physics scale below the Landau pole of around 5 TeV, due to the FCNCs constraints [5].

To break the gauge symmetry and generate the masses for particles in a correct way, the scalar content can minimally be introduced as

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with corresponding VEVs,

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This scalar sector is unique, given that it includes only two scalar triplets, the top quark gets a tree-level mass, and the p-parameter coincides with the global fit, aforementioned. Let us stress that another choice of two scalar triplets such as p and x as in [11] would lead to an unacceptably large contribution for the p-parameter [12]; additionally, this yields a vanishing tree-level mass for the top quark, which is unnaturally induced by the radiative corrections or effective interactions [5]. The VEV w breaks the 3-3-1 symmetry down to the standard model symmetry and gives the masses for the new particles, while u breaks the standard model symmetry down to SU(3)C ® U(1)q and provides the masses for the ordinary particles. To keep consistency with the standard model, we impose u ^ w. The dark sector is denoted by 0 that is an inert scalar multiplet, 0 = n', x', or a, ensured by an extra Z2 symmetry 0 ^ —0, which provides dark matter candidates [5]. Interestingly enough, the presence of 0 is crucial to have a realistic simple 3-3-1 model not only because of the dark matter solution. It provides B — L violating interactions, besides the following similar one responsible for the neutrino masses, realizing the fact that the B — L symmetry in this kind of the models is approximate (otherwise, the model is not self-consistent since the B — L and 3-3-1 symmetries are algebraically non-closed). Those interactions also separate the inert field masses and make the dark matter candidates viable.	[redacted] [redacted]

Lastly, 0 governs the p-parameter by which it is comparably with the global fit, as mentioned. In other words, the p-parameter can contain information on the dark sector.

The total Lagrangian, up to the gauge fixing and ghost terms, is obtained by

………………(9)

where F and S run over all the fermion multiplets and scalar multiplets, respectively. The covariant derivative is + igstiGiM + igTiAiM + igXXBM, where (gs,g,gX) and (GiM,AiM,BM) are the gauge couplings and gauge bosons of the 3-3-1 groups, respectively. The field strength tensors GijUV, AijUV, and B^v are correspondingly followed. The scalar potential is given by V = V,imple + Vinert, where the first term is

(10)

which is the potential of the normal scalar sector, while the second term that includes the potential of the inert scalar sector as well as the interactions between the two sectors is

like those supplied in [5] for 0 = n', x', or a, which should be kept for brevity. Lastly, the Yukawa Lagrangian takes the form,

(11)

where A is a new scale that defines the effective interactions, needed to generate appropriate masses for all the fermions [5]. All the h’s couplings conserve B — L, except for the sv coupling that violates this charge by two units. This reflects the fact B — L as an approximate symmetry, and the corresponding neutrino masses derived are reasonably small [5].

Because of the Z2 symmetry, the VEV of 0

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vanishes, <0> = 0. The gauge bosons gain masses from the VEVs of n and x, given by the Lagrangian S=nx(DM<S>)^(DM<S>). The gluons Gi have zero mass, as usual. The physical charged gauge bosons with corresponding masses are obtained by

(12)

(13)

(14)

The W boson is identical to that of the standard model, which yields u — 246 GeV. X and Y are new charged gauge bosons which have large masses in the w scale, due to w ^ u. The neutral gauge bosons with corresponding masses are achieved as [5]

(17)

(17)

where sw = e/9 = t/V 1 + 4t2, with t = gX/g, is the sine of the Weinberg angle [14]. Note that the photon field A is massless and decoupled, i.e. a physical particle, whereas Z and Z' slightly mix via a mass term, given by mZZ/ = —4/3c2 W u2 — 0.16mZ ^ m2Z/, with the aid of sw — 0.231. The mixing angle of Z-Z' is defined by t2^ = 2mZZ//(mZ/ — mZ) —
1.4 x 10-4 x (3'6Wfe^2. The Z-Z' mixing term leads to the shifts in Z, Z' masses, determined by AmZ/mZ — —1.14 x 10-5 x (3'6WeV)2 and Am|,/mZz, — 5.1 x 10-9 x (3'6WeV)4, and the deviation of the p parameter is (Ap)mixing — —AmZ/m|. All such mixing effects are infinitesimal, which can be neglected, due to w > 3.6 TeV from the FCNCs bound [5]. The Z boson is a physical particle, identical to that of the standard model, while Z' is a new neutral gauge boson with a large mass

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in the w scale. The experimental p parameter can be explained by the loop effect of the inert scalar 0, as shown in the introduction. Let us remind the reader that the loop effect of X, Y gauge bosons is negligible too [12].

Because of the Z2 symmetry, the normal scalars do not mix with the inert scalars. Also, the physical eigenstates and masses of the normal scalars are given from VSimple which are distinct from the inert sector (see also Dong et al. in [4]). Let us expand

(19)

where £ is the mixing angle of S1-S3, while 9 is that of x1-n3, obtained as tg = u/w, t2g = A3uw/(A2w2 — A1u2) ~ (A3u)/(A2w). The fields A1, A3 are massless Goldstone bosons eaten by Z, Z', respectively, GZ = A1, Gz> = A3. The fields x±±, n± are massless Goldstone bosons eaten by Y±±, W±, respectively, G±± = x±±, GW = n±. The field that is orthogonal to H±, GX = cgx± — sgn±, is massless Goldstone boson of X±. In summary, we have four massive Higgs bosons (h, H, H±), in which h is the standard model Higgs like particle with a light mass in the u scale, while the others are new Higgs bosons with large masses in the w scale. There are eight Goldstone bosons (Gz, GZ/, GW, G±±, and GX) as eaten by the corresponding eight massive gauge bosons. At the effective limit, u ^ w, it follows

Finally, let us remind the reader that the physical eigenstates and masses of the inert scalars are derived from Vjnert when n and x develop the VEVs. All these were given in [5]. The con¬ditions on the scalar

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potential parameters so that the potential is bounded from below, the VEVs u,w are definitely nonzero, the physical scalar masses are positive, the Z2 symmetry is unbroken by the vacuum (i.e. (0) = 0), were also achieved therein.

III. INTERACTION

A. Interactions of fermions with gauge bosons

The concerning interactions arise from F F^y^D^F, where we separate D? = d? + igstiGi? + igP^0 + igP^0, with P^0 = ^i=3 8 TiAi? and P^0 = T3A3? + TgAg? + tXB?. The last two terms in D? will produce the charged and neutral currents, respectively, discussed in this section. Note that since Ti(FR) = 0, the charged current includes only the left-handed fermions, while the neutral current contains both the left- and right-handed fermions.

1. Charged current

Let us work in the weak basis consisting of the weight-raising and weight-lowering oper¬ators, defined by

(21)

T± ^ U± = ^ V± = • (21) The corresponding gauge bosons are

(22)

such that

(23)

where the superscripts on the fields indicate the electric charges, while the subscripts on the operators are simply marks, and we have T- = (T+)t and so forth for U, V.

The charged current takes the form,

(24)

(26)

(27)

2. Neutral current Substituting A3/, Ag/, By in terms of Ay, Zy, Z/ into P^0, we

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obtain
(28)
The neutral current takes the form,
(29)
where / indicates all the fermions of the model, and
(30)
(31)
(32)
The values of 9V (/) and 9A(f) corresponding to Z and Z' are listed in Tables I and II.

B. Interactions of scalars with gauge bosons

Note that the interactions of the inert scalars with gauge bosons were given in [5]. There¬fore, in this work we only need to calculate the remaining interactions of the normal scalars with gauge bosons, which are given from s(DyS)t(DyS), with S = n,x. Expanding the scalar multiplets in terms of the VEVs and physical scalar fields, S = (S) + S', respectively,

TABLE I: The couplings of Z with fermions.

TABLE II: The couplings of Z' with fermions. and that they are colorless, Du = du + igPu (Pu = P^0 + P^0), the Lagrangian becomes
(33)
where the first, second, and last terms provide the couplings of two scalars with a gauge boson, two gauge bosons with a scalar, and two gauge bosons with two scalars, respectively. We shall work in a basis where all the Goldstone bosons are gauged away. In this unitary gauge, the scalar multiplets simply take the form,

where in each expansion, the first and

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second terms correspond to (S) and S', respectively. The notations for the scalar multiplets, including the following gauge bosons, in this gauge have conveniently kept unchanged, which should not be confused.

Considering the first term in the above Lagrangian,

Y [i9(d'‘S')tP,„S' + H-c.] = Y [i9 (S/S')' pCCS' + J9(S'‘S')tP,NCS' + H-c-

and substituting S', P^0, P^0 as defined above, we get the interactions of a charged or a neutral gauge boson with two normal scalars, as supplied in Table III, where and throughout the interactions are understood as vertex times coupling.

Continuously, we expand the second term,

(36)

Substituting the physical fields, the interactions of a scalar with two gauge bosons corre¬sponding to the three terms above are resulted as listed in Tables IV, V, and VI, respectively. For the third term, we have

(37)

These three terms yield the interactions of two scalars with two gauge bosons, as given in Tables VII, VIII, and IX, respectively.

C. Scalar self-interactions and Yukawa Interactions

Since we work in the unitary gauge, the scalar self-interactions include only those with the physical scalar particles. Note that the interactions between the normal scalars and inert scalars were given in [5]. Therefore, we necessarily calculate only the self-interactions of the

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TABLE III: The interaction of a gauge boson with two normal scalars.

TABLE IV: The interaction of two charged gauge bosons with a normal scalar.

normal scalars. That being said, substituting n and x from (34) into V^imple, we obtain the relevant interactions as given in Tables X and XI.

The inert scalars do not have Yukawa interaction with fermions due to Z2 symmetry. Therefore, we turn to investigate the Yukawa interactions of the normal scalars. For this

TABLE V: The interaction of a charged and a neutral gauge boson with a normal scalar.

TABLE VI: The interaction of two neutral gauge bosons with a normal scalar.

aim, we first identify the mass matrices for fermions:

where the irrelevant neutrino masses, which have not been listed, can be founded in [5]. Hence, the relevant interactions and couplings are resulted as in Tables XII, XIII, and XIV. When the above mass matrices are diagonalized, we have such similar interactions for the physical fields, where the Yukawa couplings depend only on the mass eigenvalues.

TABLE VII: The interaction of two charged gauge bosons with two scalars.

TABLE VIII: The interactions of two gauge bosons with two scalars.

IV. PHENOMENOLOGY

A. The standard model Higgs like particle

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The discovery of the Higgs particle marks the success of the LHC run I [15], and its couplings can be summarized via the combined best-fit signal strength, = 1.1 ± 0.1, which deviates 10% from the standard model value 1 [16] (see also [17] for an intriguing discussion). Let us particularly investigate the Higgs coupling to two photons that substitutes in

(42)

where the numerator is given by the considering model once measured by the experiments, while the denominator is the standard model prediction.

TABLE IX: The interaction of two neutral gauge bosons with two scalars.

The Higgs production dominantly comes from the gluon gluon fusion via top loops [18]. Hence, we can approximate a(pp ^ h) ~ a(GG ^ h) as given in Fig 1, where the new physics effects are included. Note that the (b) diagram was skipped in [19, 20]. We have

where A/ (r/) = 2 [r/ + (r/ — 1) arcsin2(v/r/)] /r2 and r/ = mh/(4m2) < 1 for f = t, J1)2)3.

The dominant contributions and new physics effects to the Higgs decay into two photons are given in Fig. 2. The decay width is

TABLE X: The self-interaction of three normal scalars

TABLE XI: The self-interaction of four normal scalars.

color factor, Q/,V,S are the electric charges, and A/ is given as before, while AV)S are [18]

(45)

where all the new particles have natural masses beyond the weak scale [5], thus TB

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= mh/(4mB) < 1, and / (TB) = arcsin2(v/rB).

The total Higgs decay width is as follows

(46)

TABLE XII: The Yukawa interactions of the standard model Higgs like particle (h).

TABLE XIII: The Yukawa interactions of the new neutral Higgs boson (H).

With the aid of [18], we obtain

1. Fermion modes:

where gf = cg+6»/c^ for / = b, c and gf = cg — (1/v^2)(w/A)2(hTw/TOr)sgt# for / (where hT is the 33 component of fr4eb in the mass eigenstates).

2. Weak-boson modes:

TABLE XIV: The Yukawa interactions of the charged Higgs boson (H±).

FIG. 1: Contributions to the Higgs production due to gluon-gluon fusion. The h-H mixing effect changes the hit coupling by cg, simultaneously couples h to the exotic quarks which run in the loop. Such two modifications of the new physics are comparable ~ (u/w)2. The h// coupling for / = t, J was normalized to the standard model coupling, i.e. h/ = — mf gf, in which gf is indicated in the relevant graph.

where = 1, = 7/12 — 10sW/9 + 40sW/27, x = mV/m|, and

3(1 - 8x + 20x2)

FIG. 2: Contributions to the decay h ^ 77. The new physics effects include the h-H mixing and the contributions of the exotic quarks, new charged gauge bosons, and charged normal and inert scalars. Hereafter, the couplings hV*V (V = W, X, Y) and hS*S (S = H±,0) are normalized to the standard model coupling, hV = ^gV and hS

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= - ^gS. Here, gV is explicitly displayed in the relevant graph, but gH± and g^ could be read off from Table X and those in [5], respectively.

The corresponding standard model Higgs-decay widths are those obtained above in the limit w ^ 0, £ ^ 0 such that r(-■ ■)SM = r(-■ ■)|0=g=O)W=TC. The fixed input parameters for estimating the signal strength are u — 246 GeV, sW — 0.231, ……., which should satisfy both the FCNCs bound and Landau pole limit. Furthermore, we have the conditions for the potential parameters,

(51)

(52)

and the others for the inert part, as supplied in [5]. The signal strength p,77 is scanned for w = 3.6, 4, 4.5, 5 TeV, when varying A1;2;4 (A3 is related to A1;2 by mh) in 0.01-2, but satisfying all the above conditions, where the coupling and mass parameters of the inert part are chosen as in [5]. The exotic quark masses are also varied from beyond the weak scale up to the TeV scale. The numerical study yields a maximal bound, p.77 < 1.06, in agreement with the data (up to the known QCD corrections). We see that the new physics is quite decoupled because the mixing angles 9 ~ u/w, £ ~ (A3u)/(2A2w) are strictly suppressed, and all the contributions of new particles to the amplitudes are proportional to (u/w)2.

B. The mixing and rare ^ decay

Let the gauge states for up-quarks u = (u1 u2 u3)T and down-quarks d = (d1 d2 d3)T. They are related to the mass eigenstates uL,R = VUL,RU'LR and dL,R = VdL,RdLR, where u' = (u c t)T and d' = (d

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s b)T, such that VUltoUVur = diag(mu, mc, mt) and VdLmdVdR = diag(md, ms,). The CKM matrix is Vckm = VULVdL. Below, we also denote q as either u or d, and q' as either u' or d'.

Since the quark generations are non-universal under the SU(3)L® U(1)X gauge symmetry, there must be corresponding tree-level FCNCs. Indeed, reconsidering the interaction of neutral gauge bosons with fermions (29), we have

(53)

[redacted]

where t = /g, Q - T3 + v/3T8 = X, and F runs over all the fermion multiplets (the sum notation was omitted and should be understood). Above, note that there is no FCNC associated with T3 and Q since all the repetitive flavors, e.g. |uaL}, or |uaR}, or {DaL}, are identical under those charges. Further, the repetitive flavors of leptons and exotic quarks are also identical under T8. Hence, there are only FCNCs associated with T8 for the ordinary quarks. That being said, the relevant interactions are

(54)

[redacted]

where we have used A8 + yJHtB = Z'/^/1 - 3tW, T8(qaR) = 0, and Tq = 2^3diag(-1, -1,1) that consists of the T8 values for either (u1L, u2L, u3L) or (d1L, d2L, d3L) flavors, respectively. Changing to the mass eigenstates yields the tree-level FCNCs,

(55)

Integrating out Z' from (55), we obtain effective interactions:

(56)

where we have used m|, — 3(f_Wt2). It is

[redacted]

noteworthy that the interactions of Z' in (29) and (55) may encounter a Landau pole, A ~ 5 TeV, at which sW (A) = 1/4 or 9x (A) = 9sW/^/1 - 4sW = ro [21]. However, the effective interactions (56) are always independent of this singularity. Such interactions contribute to meson mixings as K-K, D-D, Bd-Bd, and Bs-Bs, governed by quark pairs (q', qj) = (d, s), (u,c), (d, b), and (s,b), respectively. The strongest bound for the new physics comes from Bs-Bs mixing. See the left graph of Fig. 3 for this mixing as explained by basic Z' boson. We have [13]

(57)

Without loss of generality, let ua be flavor-diagonal, i.e. VCkm = . The CKM factor is given by |(Vd*L)32(VdL)331 — 3.9 x 10-2 [13], which implies

(58)

slightly larger than the bound given in [5]. Correspondingly, the Z' mass is bounded by mZ > 4.67 TeV, provided that sW — 0.231 is at the low energy regime of interested precesses. This mass is close to the point at which the perturbative character of the U(1)X (thus Z') interaction is lost (beyond this point the theory becomes strongly coupled and meets the singularity). Indeed, the TeV scale physics yields a larger sW closely to 1/4, and mZ/ achieved may be beyond the singularity, lying in the invalid regime of the model. This indicates that the high energy behavior of the 3-3-1 model should take the B - L gauge symmetry into account, called the 3-3-1-1 model [22], since it not only relaxes the w and mZ/ bounds [23], but also cures the non-unitarity of the 3-3-1

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model [24].
Integrating out Z' from (55) and (29) for charged leptons, we get effective interactions:
(59)
where 1 = e, p., T, and they are independent of the Landau singularity too. These interactions potentially contribute to rare semileptonic/leptonic meson decays such as B ^ K(+)/+/-, B ^ n1+/-, Bs,d ^ /+/-, and so on. Particularly, let us consider the b ^ sl+1- transition as defined by the effective interactions:
(60)
where the semileptonic operators are
(61)
and the Wilson coefficients induced by the new physics are identified as
(62)
a m^/
where note that Gf = sm-. The global fits of the Wilson coefficients to the b ^ sl+1- data have been established by several groups [25]. Some observed deviations may hint towards an interpretation of the new physics. See [8, 17, 26, 27], for instance, for recent explanations. A strong constraint on AC10 might come from Bs ^ p+p- decay [28]. The new physics contribution is demonstrated by the right graph in Fig. 3 by basic Z' boson exchange. Generalizing the results in [27], we obtain the signal strength:

(63)
where r = AC'10/C'10 (C10 = -4.2453 is the standard model Wilson coefficient) is real and bounded by 0 < r < 0.1. It leads to

Correspondingly, our model predicts AC9

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= 3AC10 = [-1.273, 0], in agreement with the model-independent global fits [25].

Note that the AC'g/AC'10 relation and bound achieved above are unlike those in [8] in spite of [= — for both the models (ours and the one in [8]). Indeed, the f/Z' couplings in the minimal 3-3-1 model (Table II) are different from those in [8] because the /R fields which are included in the lepton triplets have SU(3)L ® U(1)X charges differing from the case that they are treated as SU(3)L singlets as in [8].

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FIG. 3: Contributions to the s mixing and rare ^ ^+^- decay due to the tree-level flavor-changing coupling, Z'sb, as a character for this kind of the models.

C. New particle signatures

Recently, the ATLAS experiment at the LHC8 [29] has reported 3.4, 2.6, and 2.9a excesses, whose peaks are around 2 TeV and widths are narrow, in searches for massive res¬onances decaying into WZ, WW, and ZZ channels, respectively. Since about 20% events are shared among these channels, the resonances are not completely separated, that can be interpreted as the signature of a new boson with a mass about 2 TeV, produced in proton- proton collisions at yfs = 8 TeV, then decaying into one of the channels whose production cross-section times decay branching ratio into the gauge bosons is in 10 fb order. Very re¬cently, both the ATLAS and CMS experiments at the LHC13 have indicated the hint of a new resonance with a peak at around 750 GeV decaying into two photons, with a high local significance (about 3a), whose production cross-section times decay branching ratio into two

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photons is in 10 fb order too [30]. Although it is too early to qualify the 2 TeV and/or 750 GeV resonances as discoveries, it is worthwhile to explain any of the observations.

As discussed above, the Z' boson is more massive than the 2 TeV excesses. Therefore, it cannot be accounted for the ATLAS diboson anomalies. Examining various 3-3-1 models, the work in [31] indicates a similar conclusion. Additionally, since our model yields the Z' mass near the Landau singularity, the Drell-Yan and dijet bounds might be relaxed [32].

The new neutral Higgs boson H has the mass mH = V2A2w, which can vary from just above the weak scale to TeV scale, depending on the A2 size. For example, taking A2 = 0.01¬0.5 and w = 4 TeV due to the FCNC constraint, it leads to mH = 465-4000 GeV. Can the new Higgs H account for the 750 GeV diphoton excess (thus A2 — 0.0175)? First of all, observe that these new Higgs particles can be generated at the LHC dominantly through gluon-gluon fusion via exotic-quarks loops, and then partially decay into two high-energy photons [36]. Using — hJ/v/2mJ = 1/w (due to (40)) and Nj = 3 (the number of exotic quarks), the H coupling to gluons induced by Ja loops takes the form [33]

(65)

which is enhanced due to the number of heavy quarks and is obviously independent of the hJ strength. Because of the FCNC constraint, w > 3.9 TeV, it yields a(pp ^ H) < 1.77 x 10-2 pb at the LHC13 for mH = 750 GeV.

If the H boson decays only into two

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photons, photon and Z, and two gluons via the exotic quarks loops, we have

(66)

(67)

The gluon mode dominates, while the two others are comparable and more enhanced than those of the 3-3-1 model with right-handed neutrinos (where 192/18 changes to 2/9) due to the large electric charges for exotic quarks. Correspondingly, we have Br(H ^ yy) — 7.38 x 10-2 and Br(H ^ yZ) — 4.24 x 10-2. The model predicts = a(pp ^ H)Br(H ^ YY) < 1.3 fb and aYZ = a(pp ^ H)Br(H ^ yZ) < 0.75 fb. The cross section is slightly small to explain the 750 GeV diphoton excess. Neglecting other constraints by choosing w = 2 TeV, it follows a(pp ^ H) — 6.75 x 10-2 pb, thus — 5 fb, in agreement with the data [30] as well as the conclusion of [34]. This case yields aYZ — 2.86 fb.

We see that w < 2 TeV for the diphoton excess opposes the FCNC constraint and the other bounds aforementioned. Furthermore, H might decay into WW, ZZ, and tt due to the h-H mixing, set by the strength £ ~ (A3u)/(A2w), and into hh due to the scalar coupling, V D wHh2. We evaluate, for examples, r(H ^ WW)/r(H ^ GG) ~ 459.5 x (0.1/as)2(A3/A2)2 and r(H ^ hh)/r(H ^ GG) ~ 58.16 x (0.1/as)2(A3/A2)2.

Consequently, all these modes may reduce Br(H ^ 77) substantially, depending on A3/A2.

To avoid such low value of w as well as the potential large decays of H into the

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standard model heavy particles, we interpret the inert scalar H3 or A/3 as the excess instead of H, where H3 and A/3 are the real and imaginary parts of the third component of the inert scalar triplet 0 = x' (we still have 0 = n', ^ for dark matter), and the Z2 symmetry is omitted [5]. The x' inert triplet has the gauge quantum numbers similarly to x, but cannot develop VEV due to the potential minimization conditions as supplied in [5]. It can now couple to the exotic quarks via the Lagrangian D h^LX'^R + hJQolx'*Jsr + H.c.. The H3J„J„ couplings and Ja masses (as induced by H) are not correlated, and there is no H3-h mixing and no H3hh coupling, as expected (similarly valid for A3, but it will be skipped hereafter). The H3 coupling to gluons as induced by Ja loops is given by the effective Lagrangian:

[redacted]

a h'J 3
^wH3G-G-' <68>

Taking mH/ = 750 GeV, we have at the LHC13, a(pp ^ H3) ~ 7 x 10-2 pb if h'J/hJ ~ 0.51w/TeV = 1.98-2.54 for w = 3.9-5 TeV, respectively, which does not require a large hierarchy in the Yukawa couplings as in [34]. Note that in this case H3 dominantly decays into gluons, and Br(H3 ^ 77) = 7.38 x 10-2 and Br(H3 ^ 7Z) ~ 4.24 x 10-2 (both are induced by Ja loops, analogous to the above case). Correspondingly, a(pp ^ H3)Br(H3 ^ 77) ~ 5.16 fb fits the data. The model predicts a(pp ^ H3)Br(H3 ^ 7Z) ~ 2.97 fb.

[redacted]

Although the H3 couplings to tt, WW, ZZ, and hh are suppressed at the tree level, they

[redacted]

might still decay into these channels as induced by loops, e.g. tt (by a triangular loop of two J3 and a new gauge boson , due to gauge interactions XtJ3 as in (26)) and ZZ (by Ja loops due to the gauge interactions ZJaJa as in Table I). But, they are all rare as suppressed by the loop factor and u/w. For instance, the effective coupling, - m ceffH3tt, is obtained as
2
ceff = 96(^2 WW as desirable, where we have assumed mJ = mX for brevity.

[redacted]

In some sense, H can mainly decay into two electroweak gauge bosons, but it cannot explain the ATLAS diboson excesses [29]. This is because, at the LHC8, for mH = 2 TeV (i.e. A2 = 1/8) and w = 4 TeV, we have a(pp ^ H) ~ 4.68 x 10-2 fb as induced by Ja loops, which is too small to fit the data. Also, the inert scalars such as H3 and A/3 could not be the diboson excess. Although some of them can be enough produced by choosing appropriate h'J/hJ ratio, its decays into the electroweak bosons are very rare due to the loop factor and u/w suppressions aforementioned.

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In summary, the results in the second work of [34] are refined, and an alternative solution to the first work of [34] for the simple 3-3-1 model with inert scalars are obtained.

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V. CONCLUSION

The baryon minus lepton number (B — L) is an accident symmetry in the standard model and it always commutes with the gauge symmetry. Even, it can acts as a hidden gauge symmetry if three right-

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handed neutrinos are included. The case is different and explicit in 3-3-1 extensions, where B — L and 3-3-1 symmetries do not commute and non-closed algebraically. Consequently, either we must work with a greater gauge group to close the algebras known as 3-3-1-1 [22-24] or accepting 3-3-1 models, but B — L is an approximate symmetry and the unitarity is not ensured at a high energy scale. Interpreting inert scalar multiplets for the 3-3-1 models is a natural recognition of the last fold because it not only yields appropriate B — L violating interactions but also providing rich phenomenology such as dark matter [5], the global fit p-parameter, and the possible solution to the LHC diphoton anomaly (last two are obtained in this work). The 3-3-1 model considered in this work is with the minimal lepton and normal scalar content, and the inert sector includes n', x' as replications of the normal scalars, respectively, and a' scalar sextet.

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Because of such a special scalar sector, the model is calculable. All the gauge interactions for fermions and scalars are derived, and the self-interactions of scalars as well as Yukawa interactions are achieved. The standard model interactions are recovered in the effective limit u ^ w. It is noted that the interactions of charged leptons with Z' are not governed by the general formulae for since the right-handed charged leptons possess the T8 charge. With this at hand, we obtain the production cross-section and branching decay widths for the standard model like Higgs boson as well as the effective interactions describing

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the meson mixings and rare semileptonic/leptonic meson decays due to the Z' contribution. The new physics contributions to the standard model Higgs signal strength are strictly suppressed by (u/w)2, and in the viable parameter regime the model’s prediction is close to the standard model and in agreement with the data. The Bs — Bs mixing constrains the 3-3-1 breaking scale to be w > 3.9 TeV, while the rare Bs ^ decay data indicate mZ/ > 2.02 TeV. Our model predicts the new physics contribution to the Wilson coefficients to be ACg = 3AC10 = [—1.273, 0], in agreement with the global fits. Such results improve the previous bounds [8] since the Z'// coupling is changed as corrected. A lower bound on w from the meson mixing can be achieved since the B — L gauge interaction if included also substantially contribute as Z' [23].

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We have shown that Z' cannot be interpreted as the ATLAS diboson excesses since this particle is more massive than 2 TeV. Also, the new neutral scalar H that is responsible for the 3-3-1 symmetry breaking and the inert scalars cannot be the diboson resonances since their production cross-sections are too small in comparison to the data. The new Higgs H also cannot be the ATLAS/CMS diphoton excess since there is a discrepancy between the FCNC and collider bounds on the w scale. The inert scalar H3' or inert pseudo-scalar A3 may be naturally interpreted as the 750 GeV diphoton excess in our model since their decay modes to YY are more enhanced due to the large electric charges

[redacted]

carried by the exotic quarks. The hierarchy in the exotic quark Yukawa couplings is not necessary. The model yields a(pp ^ H3)Br(H3 ^ YZ) = 2.97 fb at the LHC13, sightly smaller than the YY production. It is emphasized that the exotic quarks and inert scalars in explaining the diphoton excess are fundamental components of the 3-3-1 model previously studied. The results as obtained obviously reveal a significant inert scalar sector, strongly corre¬lated to the simple 3-3-1 model on both the theoretical and phenomenological sides: the mathematical inconsistency with B — L symmetry is cured, the dark matter and diphoton anomaly can be explained, the p-parameter is in agreement with the global fit, and the small neutrino masses might result from the approximate B — L symmetry.	[redacted] [redacted]