



The Standard Model of Particle Physics as an effective theory from two non-universal U(1)'s

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Outline

- **Introduction**
- **The Model**
- **Constrains from Yukawa sector**
- **Solutions**
- **Benchmark Models**
- **Z' Charges**
- **Conclusions**

Introduction

The standard model of particle physics based on the local gauge group $SU(3)_c \otimes SU(2)_L \otimes U(1)_Y$ has been very successful.

However, the SM fails in explaining things as: hierarchical charged fermion masses, fermion mixing angles, charge quantization, strong CP violation, replication of families, neutrino masses and oscillations, and the matter-antimatter asymmetry of the universe. Besides, gravity is excluded from the context of the model, which also fails to provide a good candidate for the dark mater and the dark energy present in the universe.

It is therefore widely believed that the SM is not truly fundamental, the prevailing view being that the model is just an effective model. We are going to propose an extension of it; that is, a new model for three families based on the local gauge group $SU(3)_c \otimes SU(2)_L \otimes U(1)_\alpha \otimes U(1)_\beta$ where the hyper-charges of the two abelian factors are non-universal, in the sense that they are not the same for the assumed three families.

The Model

Field	$li = (\nu_i, e_i)_L^T$	ν_{iR}	e_{iR}	$qi = (u_i, d_i)_L^T$	u_{iR}	d_{iR}	$\phi_a = (\phi_a^+, \phi_a^0)^T$	σ
T_{3L}	$(\frac{1}{2}, -\frac{1}{2})^T$	0	0	$(\frac{1}{2}, -\frac{1}{2})^T$	0	0	$(\frac{1}{2}, -\frac{1}{2})^T$	0
Y	-1	0	-2	$\frac{1}{3}$	$\frac{4}{3}$	$-\frac{2}{3}$	1	0
Q	$(0, -1)^T$	0	-1	$(\frac{2}{3}, -\frac{1}{3})^T$	$\frac{2}{3}$	$-\frac{1}{3}$	$(1, 0)^T$	0
α_{fi}	α_{li}	α_{ni}	α_{ei}	α_{qi}	α_{ui}	α_{di}	$\alpha_{\phi a}$	α_σ
β_{fi}	β_{li}	$\beta_{\nu i}$	β_{ei}	β_{qi}	β_{ui}	β_{di}	$\beta_{\phi a}$	β_σ

Electric charge generator:

$$Q = T_{3L} + \frac{1}{2} (aI_\alpha + bI_\beta) ,$$

implies that the SM hyper-charge Y can be identified as

$$Y = (aI_\alpha + bI_\beta) ,$$

Covariant derivative

$$D^\mu = \partial^\mu + igT_L^j W_{jL}^\mu + i\frac{g_\alpha}{2} I_\alpha B_\alpha^\mu + i\frac{g_\beta}{2} I_\beta B_\beta^\mu ,$$

Gauge anomalies:

$$[SU(3)_c]^2 U(1)_\alpha : 2(2\alpha_{q1} - \alpha_{u1} - \alpha_{d1}) + 2\alpha_{q3} - \alpha_{u3} - \alpha_{d3} = 0 ,$$

$$[SU(3)_c]^2 U(1)_\beta : 2(2\beta_{q1} - \beta_{u1} - \beta_{d1}) + 2\beta_{q3} - \beta_{u3} - \beta_{d3} = 0 ,$$

$$[SU(2)_L]^2 U(1)_\alpha : 2(3\alpha_{q1} + \alpha_{l1}) + 3\alpha_{q3} + \alpha_{l3} = 0 ,$$

$$[SU(2)_L]^2 U(1)_\beta : 2(3\beta_{q1} + \beta_{l1}) + 3\beta_{q3} + \beta_{l3} = 0 ,$$

$$\begin{aligned} [\text{grav}]^2 U(1)_\alpha : & 2(6\alpha_{q1} - 3\alpha_{u1} - 3\alpha_{d1} + 2\alpha_{l1} - \alpha_{n1} - \alpha_{e1}) \\ & + 6\alpha_{q3} - 3\alpha_{u3} - 3\alpha_{d3} + 2\alpha_{l3} - \alpha_{n3} - \alpha_{e3} = 0 , \end{aligned}$$

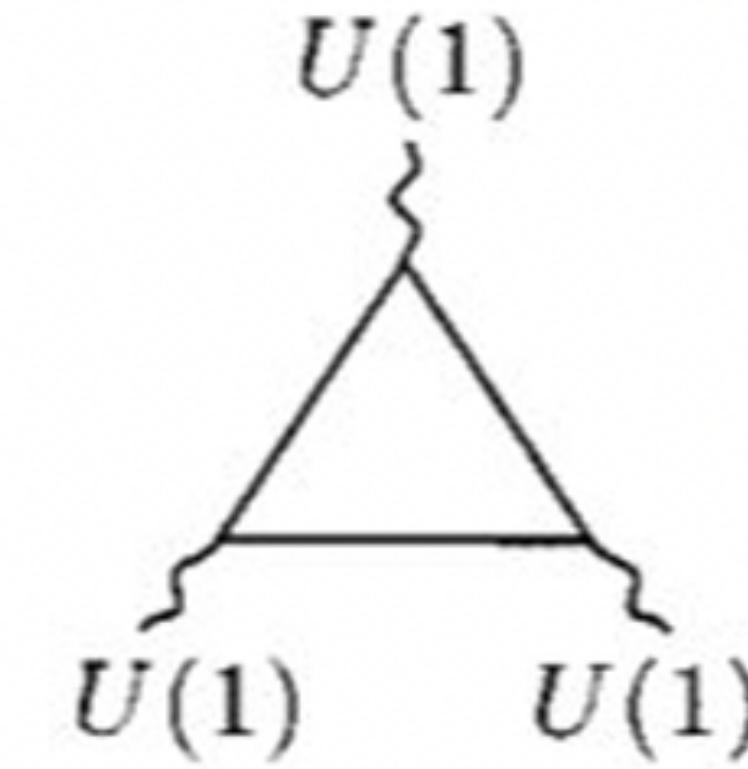
$$\begin{aligned} [\text{grav}]^2 U(1)_\beta : & 2(6\beta_{q1} - 3\beta_{u1} - 3\beta_{d1} + 2\beta_{l1} - \beta_{n1} - \beta_{e1}) \\ & + 6\beta_{q3} - 3\beta_{u3} - 3\beta_{d3} + 2\beta_{l3} - \beta_{n3} - \beta_{e3} = 0 , \end{aligned}$$

$$\begin{aligned} [U(1)_\alpha]^3 : & 2(6\alpha_{q1}^3 - 3\alpha_{u1}^3 - 3\alpha_{d1}^3 + 2\alpha_{l1}^3 - \alpha_{n1}^3 - \alpha_{e1}^3) \\ & + 6\alpha_{q3}^3 - 3\alpha_{u3}^3 - 3\alpha_{d3}^3 + 2\alpha_{l3}^3 - \alpha_{n3}^3 - \alpha_{e3}^3 = 0 , \end{aligned}$$

$$\begin{aligned} [U(1)_\beta]^3 : & 2(6\beta_{q1}^3 - 3\beta_{u1}^3 - 3\beta_{d1}^3 + 2\beta_{l1}^3 - \beta_{n1}^3 - \beta_{e1}^3) \\ & + 6\beta_{q3}^3 - 3\beta_{u3}^3 - 3\beta_{d3}^3 + 2\beta_{l3}^3 - \beta_{n3}^3 - \beta_{e3}^3 = 0 , \end{aligned}$$

$$\begin{aligned} [U(1)_\alpha]^2 U(1)_\beta : & 2(6\alpha_{q1}^2 \beta_{q1} - 3\alpha_{u1}^2 \beta_{u1} - 3\alpha_{d1}^2 \beta_{d1} + 2\alpha_{l1}^2 \beta_{l1} - \alpha_{n1}^2 \beta_{n1} - \alpha_{e1}^2 \beta_{e1}) + \\ & 6\alpha_{q3}^2 \beta_{q3} - 3\alpha_{u3}^2 \beta_{u3} - 3\alpha_{d3}^2 \beta_{d3} + 2\alpha_{l3}^2 \beta_{l3} - \alpha_{n3}^2 \beta_{n3} - \alpha_{e3}^2 \beta_{e3} = 0 , \end{aligned}$$

$$\begin{aligned} [U(1)_\beta]^2 U(1)_\alpha : & 2(6\beta_{q1}^2 \alpha_{q1} - 3\beta_{u1}^2 \alpha_{u1} - 3\beta_{d1}^2 \alpha_{d1} + 2\beta_{l1}^2 \alpha_{l1} - \beta_{n1}^2 \alpha_{n1} - \beta_{e1}^2 \alpha_{e1}) + \\ & 6\beta_{q3}^2 \alpha_{q3} - 3\beta_{u3}^2 \alpha_{u3} - 3\beta_{d3}^2 \alpha_{d3} + 2\beta_{l3}^2 \alpha_{l3} - \beta_{n3}^2 \alpha_{n3} - \beta_{e3}^2 \alpha_{e3} = 0 . \end{aligned}$$



Spontaneous symmetry breaking

$$SU(3)_c \otimes SU(2)_L \otimes U(1)_\alpha \otimes U(1)_\beta \xrightarrow{\langle \sigma \rangle} SU(3)_c \otimes SU(2)_L \otimes U(1)_Y \xrightarrow{\langle \Phi \rangle} SU(3)_c \otimes U(1)_Q,$$

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Where two new parameters α_σ and β_σ come into play which must satisfy

$$a\alpha_\sigma + b\beta_\sigma = Y_\sigma = 0.$$

When the SM-singlet scalar field σ acquires a non-vanishing vacuum expectation value (VEV) V at a large energy scale, it induces a mixing between the B_a fields.

which gives place to the SM gauge boson B associated with $U(1)_Y$ the hyper-charge and to a new massive Z' non-universal gauge boson.

$$\begin{pmatrix} B_\alpha^\mu \\ B_\beta^\mu \end{pmatrix} = \begin{pmatrix} \cos \theta & -\sin \theta \\ \sin \theta & \cos \theta \end{pmatrix} \begin{pmatrix} B^\mu \\ Z^{\mu'} \end{pmatrix}.$$

σ

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The next step is to break the SM local gauge symmetry down to $U(1)_Q$ at least two Higgs scalars must be introduced at this stage:

$$\phi_a = (H_a^+, H_a^0)^T, \quad a = 1, 3,$$

Our assumption here is that only the doublet ϕ_3 develops a VEV $\langle \phi_3 \rangle = v/\sqrt{2}$ and couples to the third family via Yukawa terms, providing with masses to all the four particles in the third family, including Dirac masses for the neutrinos

The Yukawa Lagrangian is

$$\mathcal{L}_{m3} = Y_{e3}\bar{\psi}_{l3}\langle\phi_3\rangle\psi_{e3} + Y_{n3}\bar{\psi}_{l3}\langle\tilde{\phi}_3\rangle\psi_{n3} + Y_{d3}\bar{\psi}_{q3}\langle\phi_3\rangle\psi_{d3} + Y_{u3}\bar{\psi}_{q3}\langle\tilde{\phi}_3\rangle\psi_{u3} + h.c.,$$

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equation which brings the following constraints between the abelian hyper-charge values:

$$\alpha_{\phi 3} - \alpha_{l3} + \alpha_{e3} = 0,$$

$$\beta_{\phi 3} - \beta_{l3} + \beta_{e3} = 0;$$

$$\alpha_{\phi 3} + \alpha_{l3} - \alpha_{n3} = 0,$$

$$\beta_{\phi 3} + \beta_{l3} - \beta_{e3} = 0;$$

$$\alpha_{\phi 3} - \alpha_{q3} + \alpha_{d3} = 0,$$

$$\beta_{\phi 3} - \beta_{q3} + \beta_{d3} = 0;$$

$$\alpha_{\phi 3} + \alpha_{q3} - \alpha_{u3} = 0,$$

$$\beta_{\phi 3} + \beta_{q3} - \beta_{u3} = 0.$$

A second scalar doublet ϕ_1 with abelian quantum numbers α_{ϕ_1} and β_{ϕ_1} which provides masses to the first two families must be introduced, the constraints are the same as before only we need to replace $3 \rightarrow 1$.

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A simple algebra shows that the Yukawa mass terms of these two scalar Higgs doublets brings the following set of twelve new constraint equations for the fermion α and β U(1)'s parameters:

$$\begin{array}{lll} 2\alpha_{l1} = \alpha_{n1} + \alpha_{e1}; & 2\alpha_{q1} = \alpha_{u1} + \alpha_{d1}; & \alpha_{u1} + \alpha_{e1} = \alpha_{n1} + \alpha_{d1}; \\[10pt] 2\alpha_{l3} = \alpha_{n3} + \alpha_{e3}; & 2\alpha_{q3} = \alpha_{u3} + \alpha_{d3}; & \alpha_{u3} + \alpha_{e3} = \alpha_{n3} + \alpha_{d3}; \\[10pt] 2\beta_{l1} = \beta_{n1} + \beta_{e1}; & 2\beta_{q1} = \beta_{u1} + \beta_{d1}; & \beta_{u1} + \beta_{e1} = \beta_{n1} + \beta_{d1}; \\[10pt] 2\beta_{l3} = \beta_{n3} + \beta_{e3}; & 2\beta_{q3} = \beta_{u3} + \beta_{d3}; & \beta_{u3} + \beta_{e3} = \beta_{n3} + \beta_{d3}. \end{array}$$

Solution I:

$$\alpha_{l1} = -3\alpha_{q1},$$

$$\alpha_{e1} = -\alpha_{n1} - 6\alpha_{q1},$$

$$\alpha_{u1} = \alpha_{n1} + 4\alpha_{q1},$$

$$\alpha_{d1} = -\alpha_{n1} - 2\alpha_{q1},$$

$$\alpha_{l3} = -3\alpha_{q3},$$

$$\alpha_{e3} = -\alpha_{n3} - 6\alpha_{q3},$$

$$\alpha_{u3} = \alpha_{n3} + 4\alpha_{q3},$$

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$$\beta_{u3} = \beta_{n3} + 4\beta_{q3},$$

$$\beta_{d3} = -\beta_{n3} - 2\beta_{q3}.$$

Standard model

$$U(1)_\beta \otimes U(1)_\alpha \xrightarrow{\langle \sigma \rangle} U(1)_Y,$$

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the following twelve equations must be satisfied:

$$b\beta_{l1} + a\alpha_{l1} = -1,$$

$$b\beta_{l3} + a\alpha_{l3} = -1,$$

$$b\beta_{e1} + a\alpha_{e1} = -2,$$

$$b\beta_{e3} + a\alpha_{e3} = -2,$$

$$b\beta_{q1} + a\alpha_{q1} = 1/3,$$

$$b\beta_{q3} + a\alpha_{q3} = 1/3,$$

$$b\beta_{u1} + a\alpha_{u1} = 4/3,$$

$$b\beta_{u3} + a\alpha_{u3} = 4/3,$$

$$b\beta_{d1} + a\alpha_{d1} = -2/3,$$

$$b\beta_{d3} + a\alpha_{d3} = -2/3,$$

$$b\beta_{n1} + a\alpha_{n1} = 0,$$

$$b\beta_{n3} + a\alpha_{n3} = 0,$$

The before constraints implies

$$\begin{aligned}\alpha_{q1} &= (1 - 3b\beta_{q1})/(3a), \\ \alpha_{q3} &= (1 - 3b\beta_{q3})/(3a), \\ \alpha_{n1} &= -b\beta_{n1}/a, \\ \alpha_{n3} &= -b\beta_{n3}/a.\end{aligned}$$

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We can obtain the SM, from two U(1)'s non universal. With the others two solutions one of them reproduce the same results, however, the other one can not arrive to the SM.

Another important question here is: if the scalar singlet σ is able to produce a Majorana mass for the right handed neutrinos. To do it, a set of new constraint equation must be satisfied,

$$2\alpha_{n1} + \alpha_\sigma = 0,$$

$$2\alpha_{n3} + \alpha_\sigma = 0,$$

$$\alpha_{n1} + \alpha_{n3} + \alpha_\sigma = 0,$$

$$2\beta_{n1} + \beta_\sigma = 0,$$

$$2\beta_{n3} + \beta_\sigma = 0,$$

$$\beta_{n1} + \beta_{n3} + \beta_\sigma = 0.$$

The analysis shows that in order to provide Majorana masses for the right-handed neutrinos, we must have:

$$\alpha_{n1} = \alpha_{n3} \equiv \alpha_n, \quad \text{and} \quad \beta_{n1} = \beta_{n3} \equiv \beta_n,$$

that is: universality must be present in the right-handed neutral lepton sector.

The next question is: if there are solutions for the former analysis to the case when right handed neutrinos are absent

$$\alpha_{n1} = \alpha_{n3} = \beta_{n1} = \beta_{n3} = 0$$

a

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There are two different kinds of solutions all of them functions of four free parameters β_{q_1} , β_{q_3} , a and b :

$$\begin{aligned}\alpha_{l1} &= (-1 + 3b\beta_{q1})/a; & \alpha_{l3} &= (-1 + 3b\beta_{q3})/a, \\ \beta_{l1} &= -3\beta_{q1}; & \beta_{l3} &= -3\beta_{q3}, \\ \alpha_{e1} &= 2(-1 + 3b\beta_{q1})/a; & \alpha_{e3} &= 2(-1 + 3b\beta_{q3})/a, \\ \beta_{e1} &= -6\beta_{q1}; & \beta_{e3} &= -6\beta_{q3}, \\ \alpha_{q1} &= (1 - 3b\beta_{q1})/(3a); & \alpha_{q3} &= (1 - 3b\beta_{q3})/(3a), \\ \alpha_{u1} &= 4(1 - 3b\beta_{q1})/(3a); & \alpha_{u3} &= 4(1 - 3b\beta_{q3})/(3a), \\ \beta_{u1} &= 4\beta_{q1}; & \beta_{u3} &= 4\beta_{q3}, \\ \alpha_{d1} &= 2(-1 + 3b\beta_{q1})/(3a); & \alpha_{d3} &= 2(-1 + 3b\beta_{q3})/(3a), \\ \beta_{d1} &= -2\beta_{q1}; & \beta_{d3} &= -2\beta_{q3}.\end{aligned}$$

Benchmark models

B-L model: In this case the lepton charges must be minus three times the quark charges

$$a\alpha + b\beta = U(1)_{B-L}$$

It is easy reproduce B-L charges with our model, in this case

$$\beta_{q1} = 1/3 - \alpha_{q1}, \quad \beta_{q3} = 1/3 - \alpha_{q3}, \quad \beta_{n1} = -1 - \alpha_{n1}, \quad \beta_{n3} = -1 - \alpha_{n3}.$$

and $a = b = 1$. Same results for the three solutions.

Lepton-Phobic model

For this particular model any linear combination of the charges α and β must be zero for all leptons.

$$\alpha_{q3} = -2\beta_{q1} - \beta_{q3} - 2\alpha_{q1}, \quad \alpha_{n1} = -\beta_{n1}, \quad \alpha_{n3} = -\beta_{n3};$$

Quark-Phobic model at the first two families

The charges for the first two families of quarks must be zero.

For solution I: $\beta_{q1} = -\alpha_{q1}, \quad \beta_{n1} = -\alpha_{n1}$

For solution II and III : $\beta_{q1} = -\alpha_{q1}; \quad \alpha_{n3} = -2\beta_{n1} - \beta_{n3} - 3\beta_{q3} - 2\alpha_{n1} - 3\alpha_{q3};$

Phenomenology: The charges associated with Z' for solution I:

$$Z' \rightarrow \bar{f} f$$

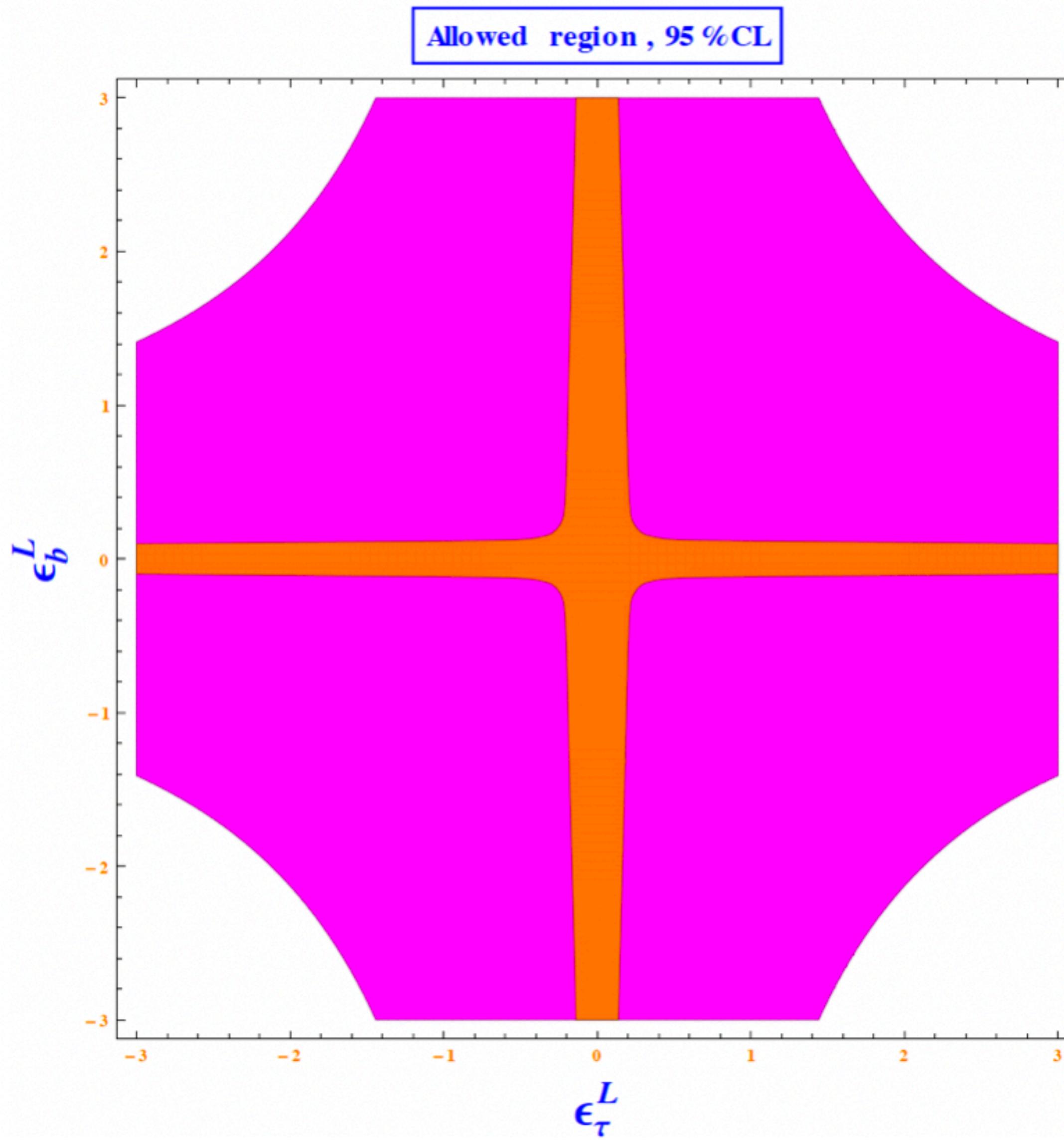
Field	Vectorial
ν_i	$\frac{1}{2}[g_\beta \cos \theta(\beta_{n1} - 3\beta_{q1}) + g_\alpha \sin \theta(1 + \beta_{n1} - 3\beta_{q1})]$
e_i	$-\frac{1}{2}[g_\beta \cos \theta(\beta_{n1} + 9\beta_{q1}) + g_\alpha \sin \theta(-3 + \beta_{n1} + 9\beta_{q1})]$
u_i	$\frac{1}{2}[g_\beta \cos \theta(\beta_{n1} + 5\beta_{q1}) + g_\alpha \sin \theta(-\frac{5}{3} + \beta_{n1} + 5\beta_{q1})]$
d_i	$-\frac{1}{2}[g_\beta \cos \theta(\beta_{n1} + \beta_{q1}) + \frac{1}{3}g_\alpha \sin \theta(-1 + 3\beta_{n1} + 3\beta_{q1})]$
ν_3	$\frac{1}{2}[g_\beta \cos \theta(\beta_{n3} - 3\beta_{q3}) + g_\alpha \sin \theta(1 + \beta_{n3} - 3\beta_{q3})]$
e_3	$-\frac{1}{2}[g_\beta \cos \theta(\beta_{n3} + 9\beta_{q3}) + g_\alpha \sin \theta(-3 + \beta_{n3} + 9\beta_{q3})]$
u_3	$\frac{1}{2}[g_\beta \cos \theta(\beta_{n3} + 5\beta_{q3}) + g_\alpha \sin \theta(-\frac{5}{3} + \beta_{n3} + 5\beta_{q3})]$
d_3	$-\frac{1}{2}[g_\beta \cos \theta(\beta_{n3} + \beta_{q3}) + \frac{1}{3}g_\alpha \sin \theta(-1 + 3\beta_{n3} + 3\beta_{q3})]$

Field	Axial
ν_i	$-\frac{1}{2}[g_\beta \cos \theta(\beta_{n1} + 3\beta_{q1}) + g_\alpha \sin \theta(-1 + \beta_{n1} + 3\beta_{q1})]$
e_i	$\frac{1}{2}[g_\beta \cos \theta(\beta_{n1} + 3\beta_{q1}) + g_\alpha \sin \theta(-1 + \beta_{n1} + 3\beta_{q1})]$
u_i	$-\frac{1}{2}[g_\beta \cos \theta(\beta_{n1} + 3\beta_{q1}) + g_\alpha \sin \theta(-1 + \beta_{n1} + 3\beta_{q1})]$
d_i	$\frac{1}{2}[g_\beta \cos \theta(\beta_{n1} + 3\beta_{q1}) + g_\alpha \sin \theta(-1 + \beta_{n1} + 3\beta_{q1})]$
ν_3	$-\frac{1}{2}[g_\beta \cos \theta(\beta_{n3} + 3\beta_{q3}) + g_\alpha \sin \theta(-1 + \beta_{n3} + 3\beta_{q3})]$
e_3	$\frac{1}{2}[g_\beta \cos \theta(\beta_{n3} + 3\beta_{q3}) + g_\alpha \sin \theta(-1 + \beta_{n3} + 3\beta_{q3})]$
u_3	$-\frac{1}{2}[g_\beta \cos \theta(\beta_{n3} + 3\beta_{q3}) + g_\alpha \sin \theta(-1 + \beta_{n3} + 3\beta_{q3})]$
d_3	$\frac{1}{2}[g_\beta \cos \theta(\beta_{n3} + 3\beta_{q3}) + g_\alpha \sin \theta(-1 + \beta_{n3} + 3\beta_{q3})]$

Z' models with zero couplings to the SM particles of the first family.

We obtain the allowed regions in the parameter space for Z' masses : 1 TeV, and 3 TeV.

We obtain these limits from the intersection of the 95%CL upper limit on the cross-section from searches of high-mass ditau resonances at the ATLAS experiment and the theoretical cross-section for the process.



Conclusions

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- in this model is necessary to have one scalar singlet and two scalar doublets. The first one is responsible to break the two U(1)'s to SM hyper-charge and to generate the mass to Z' boson, and the others one to break the SM to $SU(3)_c \otimes U(1)_Q$ and generate the masses of the fermions.

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- We can obtain a variety of benchmark models, as was shown, this implies that the model analyzed here is more general.

References

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Gracias.

To check the validity of our analysis, let us calculate Y_e for example, using solution A, combined with the former results:

$$\begin{aligned} Y_e &= a\alpha_{e1} + b\beta_{e1} \\ &= -a(\alpha_{n1} + 6\alpha_{q1}) - b(\beta_{n1} + 6\beta_{q1}) \\ &= -a(\alpha_{n1} + 6\alpha_{q1}) + b\left(\frac{a}{b}\right)\alpha_{n1} - 6\left(\frac{1 - 3a\alpha_{q1}}{3}\right) = -2, \end{aligned}$$

Solution II

$$\begin{aligned} \alpha_{l1} &= (\alpha_{n1} - \alpha_{n3} - 6\alpha_{q1} - 3\alpha_{q3})/3, \\ \beta_{l1} &= (\beta_{n1} - \beta_{n3} - 6\beta_{q1} - 3\beta_{q3})/3, \\ \alpha_{e1} &= (-\alpha_{n1} - 2\alpha_{n3} - 12\alpha_{q1} - 6\alpha_{q3})/3, \\ \beta_{e1} &= (-\beta_{n1} - 2\beta_{n3} - 12\beta_{q1} - 6\beta_{q3})/3 \\ \alpha_{u1} &= (2\alpha_{n1} + \alpha_{n3} + 9\alpha_{q1} + 3\alpha_{q3})/3, \\ \beta_{u1} &= (2\beta_{n1} + \beta_{n3} + 9\beta_{q1} + 3\beta_{q3})/3, \\ \alpha_{d1} &= (-2\alpha_{n1} - \alpha_{n3} - 3\alpha_{q1} - 3\alpha_{q3})/3, \\ \beta_{d1} &= (-2\beta_{n1} - \beta_{n3} - 3\beta_{q1} - 3\beta_{q3})/3, \\ \alpha_{l3} &= (-2\alpha_{n1} + 2\alpha_{n3} - 6\alpha_{q1} - 3\alpha_{q3})/3, \\ \beta_{l3} &= (-2\beta_{n1} + 2\beta_{n3} - 6\beta_{q1} - 3\beta_{q3})/3, \\ \alpha_{e3} &= (-4\alpha_{n1} + \alpha_{n3} - 12\alpha_{q1} - 6\alpha_{q3})/3 \\ \beta_{e3} &= (-4\beta_{n1} + \beta_{n3} - 12\beta_{q1} - 6\beta_{q3})/3, \\ \alpha_{u3} &= (2\alpha_{n1} + \alpha_{n3} + 6\alpha_{q1} + 6\alpha_{q3})/3 \\ \beta_{u3} &= (2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 6\beta_{q3})/3, \\ \alpha_{d3} &= (-2\alpha_{n1} - \alpha_{n3} - 6\alpha_{q1})/3, \\ \beta_{d3} &= (-2\beta_{n1} - \beta_{n3} - 6\beta_{q1})/3. \end{aligned}$$

Solution III

$$\begin{aligned} \alpha_{l1} &= -\alpha_{n1} - \alpha_{n3} - 6\alpha_{q1} - 3\alpha_{q3}, \\ \beta_{l1} &= -\beta_{n1} - \beta_{n3} - 6\beta_{q1} - 3\beta_{q3}, \\ \alpha_{e1} &= -3\alpha_{n1} - 2\alpha_{n3} - 12\alpha_{q1} - 6\alpha_{q3}, \\ \beta_{e1} &= -3\beta_{n1} - 2\beta_{n3} - 12\beta_{q1} - 6\beta_{q3}, \\ \alpha_{u1} &= 2\alpha_{n1} + \alpha_{n3} + 7\alpha_{q1} + 3\alpha_{q3}, \\ \beta_{u1} &= 2\beta_{n1} + \beta_{n3} + 7\beta_{q1} + 3\beta_{q3}, \\ \alpha_{d1} &= -2\alpha_{n1} - \alpha_{n3} - 5\alpha_{q1} - 3\alpha_{q3}, \\ \beta_{d1} &= -2\beta_{n1} - \beta_{n3} - 5\beta_{q1} - 3\beta_{q3}, \\ \alpha_{l3} &= 2\alpha_{n1} + 2\alpha_{n3} + 6\alpha_{q1} + 3\alpha_{q3}, \\ \beta_{l3} &= 2\beta_{n1} + 2\beta_{n3} + 6\beta_{q1} + 3\beta_{q3}, \\ \alpha_{e3} &= 4\alpha_{n1} + 3\alpha_{n3} + 12\alpha_{q1} + 6\alpha_{q3}, \\ \beta_{e3} &= 4\beta_{n1} + 3\beta_{n3} + 12\beta_{q1} + 6\beta_{q3}, \\ \alpha_{u3} &= -2\alpha_{n1} - \alpha_{n3} - 6\alpha_{q1} - 2\alpha_{q3}, \\ \beta_{u3} &= -2\beta_{n1} - \beta_{n3} - 6\beta_{q1} - 2\beta_{q3}, \\ \alpha_{d3} &= 2\alpha_{n1} + \alpha_{n3} + 6\alpha_{q1} + 4\alpha_{q3}, \\ \beta_{d3} &= 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 4\beta_{q3}. \end{aligned}$$

Without neutrinos

Solution I

$$\begin{aligned}
 \alpha_{l1} &= \alpha_{l3} = (-1 + 2b\beta_{q1} + b\beta_{q3})/a, \\
 \beta_{l1} &= \beta_{l3} = -2\beta_{q1} - \beta_{q3}, \\
 \alpha_{e1} &= \alpha_{e3} = 2(-1 + 2b\beta_{q1} + b\beta_{q3})/a, \\
 \beta_{e1} &= \beta_{e3} = -2(2\beta_{q1} + \beta_{q3}), \\
 \alpha_{q1} &= (1 - 3b\beta_{q1})/(3a), \\
 \alpha_{q3} &= (1 - 3b\beta_{q3})/(3a), \\
 \alpha_{u1} &= (4 - 9b\beta_{q1} - 3b\beta_{q3})/(3a), \\
 \alpha_{u3} &= (4 - 6b\beta_{q1} - 6b\beta_{q3})/(3a), \\
 \beta_{u1} &= 3\beta_{q1} + \beta_{q3}, \\
 \beta_{u3} &= 2(\beta_{q1} + \beta_{q3}), \\
 \alpha_{d1} &= (-2 + 3b\beta_{q1} + 3b\beta_{q3})/(3a), \\
 \alpha_{d3} &= 2(-1 + 3b\beta_{q1})/(3a), \\
 \beta_{d1} &= -\beta_{q1} - \beta_{q3}, \\
 \beta_{d3} &= -2\beta_{q1},
 \end{aligned}$$

Solution II

$$\begin{aligned}
 \alpha_{l1} &= (-1 + 3b\beta_{q1})/a; & \alpha_{l3} &= (-1 + 3b\beta_{q3})/a, \\
 \beta_{l1} &= -3\beta_{q1}; & \beta_{l3} &= -3\beta_{q3}, \\
 \alpha_{e1} &= 2(-1 + 3b\beta_{q1})/a; & \alpha_{e3} &= 2(-1 + 3b\beta_{q3})/a, \\
 \beta_{e1} &= -6\beta_{q1}; & \beta_{e3} &= -6\beta_{q3}, \\
 \alpha_{q1} &= (1 - 3b\beta_{q1})/(3a); & \alpha_{q3} &= (1 - 3b\beta_{q3})/(3a), \\
 \alpha_{u1} &= 4(1 - 3b\beta_{q1})/(3a); & \alpha_{u3} &= 4(1 - 3b\beta_{q3})/(3a), \\
 \beta_{u1} &= 4\beta_{q1}; & \beta_{u3} &= 4\beta_{q3}, \\
 \alpha_{d1} &= 2(-1 + 3b\beta_{q1})/(3a); & \alpha_{d3} &= 2(-1 + 3b\beta_{q3})/(3a), \\
 \beta_{d1} &= -2\beta_{q1}; & \beta_{d3} &= -2\beta_{q3}.
 \end{aligned}$$

Charges Z', solution II

Field	Axial
ν_i	$-\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-3 + 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3})]$
e_i	$\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-3 + 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3})]$
u_i	$-\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-3 + 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3})]$
d_i	$\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-3 + 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3})]$
ν_3	$-\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-3 + 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3})]$
e_3	$\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-3 + 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3})]$
u_3	$-\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-3 + 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3})]$
d_3	$\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-3 + 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3})]$

Field	Vectorial
ν_i	$\frac{1}{6}[g_\beta \cos \theta(4\beta_{n1} - \beta_{n3} - 6\beta_{q1} - 3\beta_{q3}) + g_\alpha \sin \theta(3 + 4\beta_{n1} - \beta_{n3} - 6\beta_{q1} - 3\beta_{q3})]$
e_i	$-\frac{1}{2}[g_\beta \cos \theta(\beta_{n3} + 6\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-3 + \beta_{n3} + 6\beta_{q1} + 3\beta_{q3})]$
u_i	$\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 12\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-5 + 2\beta_{n1} + \beta_{n3} + 12\beta_{q1} + 3\beta_{q3})]$
d_i	$-\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 3\beta_{q3}) + g_\alpha \sin \theta(-1 + 2\beta_{n1} + \beta_{n3} + 3\beta_{q3})]$
ν_3	$-\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} - 5\beta_{n3} + 6\beta_{q1} + 3\beta_{q3}) + g_\alpha \sin \theta(-3 + 2\beta_{n1} - 5\beta_{n3} + 6\beta_{q1} + 3\beta_{q3})]$
e_3	$\frac{1}{2}[g_\beta \cos \theta(-2\beta_{n1} + \beta_{n3} - 6\beta_{q1} - 3\beta_{q3}) + g_\alpha \sin \theta(-3 + 2\beta_{n1} + \beta_{n3} - 6\beta_{q1} - 3\beta_{q3})]$
u_3	$\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 9\beta_{q3}) + g_\alpha \sin \theta(-5 + 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} + 9\beta_{q3})]$
d_3	$-\frac{1}{6}[g_\beta \cos \theta(2\beta_{n1} + \beta_{n3} + 6\beta_{q1} - 3\beta_{q3}) + g_\alpha \sin \theta(-1 + 2\beta_{n1} + \beta_{n3} + 6\beta_{q1} - 3\beta_{q3})]$