The Observed Diphoton Excess in F-theory Inspired Heterotic String-Derived Model

Johar M. Ashfaque

Dept. of Mathematical Sciences, University of Liverpool, Liverpool L69 7ZL, UK

Abstract

The production and the subsequent decay of the SM singlet via heavy vector–like colour triplets and electroweak doublets in one–loop diagrams can shed light on the recent observation of diphoton excess at the LHC. In this paper, the $E_6$ GUT is considered in the F-theory setting where the $E_6$ is broken by making use of the spectral cover construction and by turning on the hypercharge gauge flux. This paper is based on the results presented in [1–3] which will be reviewed briefly. Here, by following the F-theory approach, akin to [26–28], we present a study of the flipped $SO(10)$ model embedded completely in the $E_6$ GUT but with a different accommodation of the SM representations in the $27$ of $E_6$. 

1email address: jauhar@liv.ac.uk
1 Introduction

The recent observation of diphoton excess at the LHC reported by the ATLAS [5] and CMS [6] collaborations can be understood through the production and the subsequent decay of a SM singlet via heavy vector–like colour triplets and electroweak doublets in one–loop diagrams has sparked significant interest [23].

The Type IIB superstring theory admits a class of non-perturbative compactifications that go by the name of F-theory [7–9]. To break a GUT symmetry in F-theory models, one can either use Wilson lines [14, 22] or introduce a supersymmetric $U(1)$ flux corresponding to a fractional line bundle [15–20]. In local models, an Abelian or a non-Abelian gauge flux of the rank higher than two may be turned on on the bulk to break the gauge group [15]. There are two kinds of rank three fluxes, $U(1)^3$ and $SU(2) \times U(1)^2$, both embedded in the $E_6$ gauge group with commutants including the Standard Model (SM) gauge structure. For simplicity, we will focus on $U(1)^3$.

The aim of this paper is to present a study of the flipped $SO(10)$ model embedded completely in the $E_6$ GUT but with a different accommodation of the SM representations in the 27 of $E_6$ in a string-derived heterotic low-energy effective model constructed in the free fermionic formulation. The chiral spectrum of the model will be seen to form complete $E_6$ representations.

2 A String-Derived Low-Energy Effective Model

The string-derived model in [24] was constructed in the free fermionic formulation [21] of the four-dimensional heterotic string. The complete details along with the the massless spectrum and the superpotential can be found in [24] and are therefore omitted here. The chiral spectrum of the model, [24], forms complete $E_6$ representations, whereas the additional vector–like multiplets may reside in incomplete multiplets. This is in fact an additional important property of the model, which affects compatibility with the gauge coupling data. Space-time vector bosons are obtained solely from the untwisted sector and generate the observable and hidden gauge symmetries:

\[
\text{observable : } \quad SO(6) \times SO(4) \times U(1)_1 \times U(1)_2 \times U(1)_3 \\
\text{hidden : } \quad SO(4)^2 \times SO(8) .
\]

The $E_6$ combination being

\[
U(1)_\zeta = U(1)_1 + U(1)_2 + U(1)_3 ,
\]

which is anomaly free whereas the orthogonal combinations of $U(1)_{1,2,3}$ are anomalous. The model also contains vector–like states that transform under the hidden $SU(2)^4 \times SO(8)$ group factors, with charges $Q_\zeta = \pm 1$ or $Q_\zeta = 0$. 

2
Here we consider the PS breaking scale to be in the vicinity of the string scale where the VEVs of the heavy Higgs fields that break the PS gauge group leave an unbroken $U(1)_{Z'}$ symmetry given by

$$U(1)_{Z'} = \frac{1}{2} U(1)_{B-L} - \frac{2}{3} U(1)_{T_{3R}} - \frac{5}{3} U(1)_{\zeta} \notin SO(10),$$ \hspace{1cm} (2.2)

which can be found to remain unbroken down to low scales provided that $U(1)_{\zeta}$ is anomaly free. Cancellation of the anomalies requires that the additional vector–like quarks and leptons, that arise from the 10 of $SO(10)$, as well as the $SO(10)$ singlet in the 27 of $E_6$, remain in the light spectrum. The spectrum below the PS breaking scale is displayed schematically in table 1. The spectrum is taken to be supersymmetric down to the TeV scale. As in the MSSM, compatibility of gauge coupling unification with the experimental data requires the existence of one vector–like pair of Higgs doublets, beyond the number of vector–like triplets.

| Field | $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{Z'}$ quantum numbers |
|-------|--------------------------------------------------|
| $Q^i_L$ | 3 2 \hspace{1cm} $+\frac{1}{6}$ \hspace{1cm} $-\frac{2}{3}$ |
| $u^i_L$ | $\bar{3}$ 1 \hspace{1cm} $-\frac{2}{3}$ \hspace{1cm} $-\frac{2}{3}$ |
| $d^i_L$ | $\bar{3}$ 1 \hspace{1cm} $+\frac{1}{3}$ \hspace{1cm} $-\frac{4}{3}$ |
| $e^i_L$ | 1 1 \hspace{1cm} $+1$ \hspace{1cm} $-\frac{2}{3}$ |
| $L^i_L$ | 1 2 \hspace{1cm} $-\frac{1}{2}$ \hspace{1cm} $-\frac{4}{3}$ |
| $D^i$ | 3 1 \hspace{1cm} $-\frac{1}{3}$ \hspace{1cm} $+\frac{4}{3}$ |
| $\bar{D}^i$ | $\bar{3}$ 1 \hspace{1cm} $+\frac{4}{3}$ \hspace{1cm} $2$ |
| $H^i$ | 1 2 \hspace{1cm} $-\frac{1}{2}$ \hspace{1cm} $2$ |
| $\bar{H}^i$ | 1 2 \hspace{1cm} $+\frac{4}{3}$ \hspace{1cm} $+\frac{4}{3}$ |
| $S^i$ | 1 1 \hspace{1cm} 0 \hspace{1cm} $-\frac{10}{3}$ |
| $h$ | 1 2 \hspace{1cm} $-\frac{1}{2}$ \hspace{1cm} $-\frac{4}{3}$ |
| $\bar{h}$ | 1 2 \hspace{1cm} $+\frac{1}{2}$ \hspace{1cm} $+\frac{4}{3}$ |
| $\phi$ | 1 1 \hspace{1cm} 0 \hspace{1cm} $-\frac{5}{3}$ |
| $\bar{\phi}$ | 1 1 \hspace{1cm} 0 \hspace{1cm} $+\frac{5}{3}$ |
| $\zeta^i$ | 1 1 \hspace{1cm} 0 \hspace{1cm} 0 |

Table 1: Spectrum and $SU(3)_C \times SU(2)_L \times U(1)_Y \times U(1)_{Z'}$ quantum numbers, with $i = 1, 2, 3$ for the three light generations. The charges are displayed in the normalisation used in free fermionic heterotic–string models.
3 The $E_6$ Singularity

$$E_8 \supset E_6 \times SU(3)_\perp \rightarrow E_6 \times U(1)_\perp^2$$

with

$$248 \rightarrow (78, 1) + (1, 8) + (27, 3) + (27, 3)$$

In accordance with the standard terminology, the $SU(3)_\perp$ factor is considered as the group ‘perpendicular’ to the $E_6$ GUT divisor. In what follows assume semi-local approach where the $E_6$ representations transform non-trivially under the $SU(3)_\perp$. In the spectral cover approach the $E_6$ representations are distinguished by the weights $t_{1,2,3}$ of the $SU(3)_\perp$ Cartan subalgebra subject to the traceless condition

$$\sum_{i=1}^{3} t_i = 0$$

while the $SU(3)_\perp$ adjoint decomposes into singlets $1_{t_i-t_j} \equiv \theta_{ij}$.

The $E_6$ content consists of three $27$s (and $\overline{27}$s) plus eight singlet matter curves. In terms of the weight vectors $t_i$, $i = 1, 2, 3$ of $SU(3)_\perp$ the equations of these curves are

$$\sum_{27} t_i = 0,$$

$$\sum_{1} \pm (t_i - t_j) = 0 \quad i \neq j .$$

Under the decomposition $E_6 \rightarrow SO(10) \times U(1)_\zeta$, following from table II the relevant $E_6$ representations decompose as follows

$$27 \rightarrow 16_{+1/2} + 10_{-1} + 1_{+2},$$

$$\overline{27} \rightarrow 16_{-1/2} + \overline{10}_{+1} + 1_{-2}.$$

The $E_6$ GUT symmetry can be broken following [10] as

$$E_6 \rightarrow SO(10) \times U(1)_\zeta$$

$$\rightarrow [SU(5) \times U(1)_{\zeta'}] \times U(1)_\zeta$$

$$\rightarrow [SU(3) \times SU(2) \times U(1)_{\zeta''}] \times U(1)_{\zeta'} \times U(1)_\zeta$$

and the SM representations are accommodated in the $27$ of $E_6$ as

$$27 = \begin{cases} 
16_{+1/2} & \mathcal{F}_{\mathcal{L}} + \mathcal{F}_{\mathcal{R}} = (Q, u^c, d^c, L, e^c, N) \\
10_{-1} & \mathcal{D} + \mathcal{H} \\
1_{+2} & S \rightarrow S
\end{cases}.$$

\(^2\)We introduce the notation $(1, 8) \rightarrow \theta_{ij}.$
4 The Observed Diphoton Excess

Implementing the $\mathbb{Z}_2$ monodromy via the binomial-monomial factorization, we have

\[
\begin{bmatrix}
  t_1 \\
  t_2 \\
  t_3
\end{bmatrix}
\]

and the following relations between the eight singlets

\[
\begin{align*}
\theta_{12} &= \theta_{21} \equiv \theta_0 \\
\theta_{23} &= \theta_{13} \\
\theta_{32} &= \theta_{31} \leftrightarrow S
\end{align*}
\]

where we identify 750 GeV resonance $S$ with the singlet $\theta_{32} = \theta_{31}$ which couples to vector pairs.

As mentioned in [2,24], in the low-energy regime, the superpotential provides different interaction terms of the singlet fields $S_i$ and $\zeta_i$ which can be extracted from table 1 among them we have the following

\[
\lambda^{ijk}_D S_i D_j \bar{D}_k + \lambda^{ijk}_H S_i H_j \bar{H}_k + \lambda^{ij}_h S_i H_j \bar{h} + \eta^{i}_D \zeta_i D \bar{D} + \eta^{i}_h \zeta_i \bar{h} \bar{h}.
\] (4.1)

5 Conclusions

In this paper, using Abelian fluxes to realise the $E_6$ GUT symmetry breaking, we presented a study of the flipped $SO(10)$ model embedded completely in the $E_6$ GUT but with a different accommodation of the SM representations in the 27 of $E_6$. Moreover, the production and the subsequent decay of the SM singlet via heavy vector–like colour triplets and electroweak doublets in one–loop diagrams can shed light on the recent LHC-observed diphoton excess, which in effect will be able to provide pivotal evidence in understanding the fundamental origins of the SM.

6 Acknowledgements

J. M. A. would like to thank the String Phenomenology 2016 organisers hosted in Ioannina and String-Math 2016 organisers hosted in Paris for their warm hospitality.

References

[1] A. E. Faraggi and J. Rizos, “The 750 GeV di-photon LHC excess and extra $Z$’s in heterotic-string derived models,” Eur. Phys. J. C 76 (2016) no.3, 170.
[2] J. Ashfaque, L. Delle Rose, A. E. Faraggi and C. Marzo, “The LHC di-photon excess and Gauge Coupling Unification in Extra Z' Heterotic-String Derived Models,” arXiv:1606.01052 [hep-ph].

[3] P. Athanasopoulos, A. E. Faraggi and V. M. Mehta, “Light Z in heterotic string standardlike models,” Phys. Rev. D 89 (2014) no.10, 105023.

[4] D.J. Gross, J.A. Harvey, E.J. Martinec and R. Rohm, Nucl. Phys. B267 (1986) 75.

[5] ATLAS Collaboration, G. Aad et al, ATLAS–CONF–2015–081.

[6] CMS Collaboration, S. Chatrchyan et al, CMS PAS EXO–15–004.

[7] C. Vafa, “Evidence for F theory”, Nucl. Phys. B 469 (1996).

[8] D. R. Morrison and C. Vafa, “Compactifications of F theory on Calabi-Yau threefolds. 1”, Nucl. Phys. B 473 (1996).

[9] D. R. Morrison and C. Vafa, “Compactifications of F theory on Calabi-Yau threefolds. 2”, Nucl. Phys. B 476 (1996).

[10] J. L. Hewett and T. G. Rizzo, “Low-Energy Phenomenology of Superstring Inspired E(6) Models,” Phys. Rept. 183 (1989) 193.

[11] J. C. Callaghan and S. F. King, “E_6 Models from F-theory”, JHEP 1304 (2013).

[12] C. M. Chen and Y. C. Chung, “On F-theory E_6 GUTs”, JHEP 1103 (2011) 129 (2011).

[13] M. Drissi El Bouzaidi and S. Nassiri, “Breaking $E_6$ via trinification in F-theory”, Fortsch. Phys. 63 (2015).

[14] C. Beasley, J. J. Heckman and C. Vafa, “GUTs and Exceptional Branes in F-theory - I”, JHEP 0901 (2009).

[15] C. Beasley, J. J. Heckman and C. Vafa, “GUTs and Exceptional Branes in F-theory - II: Experimental Predictions”, JHEP 0901 (2009).

[16] J. Marsano, N. Saulina and S. Schafer-Nameki, “F-theory Compactifications for Supersymmetric GUTs”, JHEP 0908 (2009).

[17] J. Marsano, N. Saulina and S. Schafer-Nameki, “Monodromies, Fluxes, and Compact Three-Generation F-theory GUTs”, JHEP 0908 (2009).

[18] J. Marsano, N. Saulina and S. Schafer-Nameki, “Compact F-theory GUTs with U(1) (PQ)”, JHEP 1004 (2010) 095 doi:10.1007/JHEP04(2010).
[19] C. M. Chen and Y. C. Chung, “Flipped SU(5) GUTs from $E_8$ Singularities in F-theory”, JHEP 1103 (2011).

[20] C. M. Chen, J. Knapp, M. Kreuzer and C. Mayrhofer, “Global SO(10) F-theory GUTs”, JHEP 1010 (2010).

[21] H. Kawai, D.C. Lewellen, and S.H.-H. Tye, Nucl. Phys. B288 (1987) 1;
I. Antoniadis, C. Bachas, and C. Kounnas, Nucl. Phys. B289 (1987) 87;
I. Antoniadis and C. Bachas, Nucl. Phys. B289 (1987) 87.

[22] Y. C. Chung, “Abelian Gauge Fluxes and Local Models in F-Theory”, JHEP 1003 (2010) 006

[23] For a partial list see e.g.:
K. Harigaya and Y. Nomura, arXiv:1512.04850;
A. Pilafsis, arXiv:1512.04931;
R. Franceschini et al., arXiv:1512.04933;
S. Di Chiara, L. Marzola and M. Raidal, arXiv:1512.04939;
S.D. McDermott, P. Meade and H. Ramani, arXiv:1512.05326;
J. Ellis et al, arXiv:1512.05327;
R.S. Gupta et al, arXiv:1512.05332;
Q.H. Cao et al, arXiv:1512.05542; arxiv:1512.08441;
A. Kobakhidze et al, arXiv:1512.05585;
R. Martinez, F. Ochoa and C.F. Sierra, arXiv:1512.05617;
J.M. No, V. Sanz and J. Setford, arXiv:1512.05700;
W. Chao, R. Huo and J.H. Yu, arXiv:1512.05738;
L. Bian, N. Chen, D. Liu and J. Shu, arXiv:1512.05759;
J. Chakrabortty et al, arXiv:1512.05767;
A. Falkowski, O. Slone and T. Volansky, arXiv:1512.05777;
D. Aloni et al, arXiv:1512.05778;
W. Chao, arXiv:1512.06297;
S. Chang, arXiv:1512.06426;
R. Ding, L. Huang, T. Li and B. Zhu, arXiv:1512.06560;
X.F. Han, L. Wang, arXiv:1512.06587;
T.F. Feng, X.Q. Li, H.B. Zhang and S.M. Zhao, arXiv:1512.06696;
F. Wang, L. Wu, J.M. Yang and M. Zhang, arXiv:1512.06715;
F.P. Huang, C.S. Li, Z.L. Liu and Y. Wang, arXiv:1512.06732;
M. Bauer and M. Neubert, arXiv:1512.06828;
M. Chala, M. Duerr, F. Kahlhoefer and K. Schmidt-Hoberg, arXiv:1512.06833;
S.M. Boucenna, S. Morisi and A. Vicente, arXiv:1512.06878;
C.W. Murphy, arXiv:1512.06976;
G.M. Pelaggi, A. Strumia and E. Vigiani, arXiv:1512.07225;
J. de Blas, J. Santiago and R. Vega-Morales, arXiv:1512.07229;
A. Belyaev et al, arXiv:1512.07242;
P.S.B. Dev and D. Teresi, arXiv:1512.07243;
K.M. Patel and P. Sharma, arXiv:1512.07468;
S. Chakraborty, A. Chakraborty and S. Raychaudhuri, arXiv:1512.07527;
W. Altmannshofer et al, arXiv:1512.07616;
B.C. Allanach, P.S.B. Dev, S.A. Renner and K. Sakurai, arXiv:1512.07645;
N. Craig, P. Draper, C. Kilic and S. Thomas, arXiv:1512.07733;
J.A. Casas, J.R. Espinosa and J.M. Moreno, arXiv:1512.07895;
L.J. Hall, K. Harigaya and Y. Nomura, arXiv:1512.07904;
A. Salvio and A. Mazumdar, arXiv:1512.08184;
F. Wang et al, arXiv:1512.08434;
X. J. Bi et al, arXiv:1512.08497;
F. Goertz, J.F. Kamenik, A. Katz and M. Nardecchia, arXiv:1512.08500;
P.S.B. Dev, R.N. Mohapatra and Y. Zhang, arXiv:1512.08507;
S. Kanemura, N. Machida, S. Odori and T. Shindou, arXiv:1512.09053;
I. Low and J. Lykken, arXiv:1512.09089;
A.E.C. Hernndez, arXiv:1512.09092;
Y. Jiang, Y.Y. Li and T. Liu, arXiv:1512.09127;
K. Kaneta, S. Kang and H. S. Lee, arXiv:1512.09129;
L. Marzola et al, arXiv:1512.09136;
X.F. Han et al, arXiv:1601.00534;
W. Chao, arXiv:1601.00633;
T. Modak, S. Sadhukhan and R. Srivastava, arXiv:1601.00836;
F.F. Deppisch et al, arXiv:1601.00952;
I. Sahin, arXiv:1601.01676;
R. Ding, Z.L. Han, Y. Liao and X. D. Ma, arXiv:1601.02714;
T. Nomura and H. Okada, arXiv:1601.04516;
X.F. Han, L. Wang and J.M. Yang, arXiv:1601.04954;
D.B. Franzosi and M.T. Frandsen, arXiv:1601.05357;
U. Aydemir and T. Mandal, arXiv:1601.06761;
J. Shu and J. Yepes, arXiv:1601.06891;
J. Kawamura and Y. Omura, arXiv:1601.07396;
L. Aparicio, A. Azatov, E. Hardy and A. Romanino, arXiv:1602.00949;
R. Ding et al, arXiv:1602.00977;
K.J. Bae, M. Endo, K. Hamaguchi and T. Moroi, arXiv:1602.03653;
F. Staub et al., arXiv:1602.05581;
M. Badziak, M. Olechowski, S. Pokorski and K. Sakurai, arXiv:1603.02203;
R. Franceschini et al, arXiv:1604.06446;
K.J. Bae, C.R. Chen, K. Hamaguchi and I. Low, arXiv:1604.07941;
B.G. Sidharth et al, arXiv:1605.01169;
A. E. Crcamo Hernndez and I. Niandic, arXiv:1512.07165;
C. Arbelez et al, arXiv:1602.03607;
A. E. CremoHerndez et al, arXiv:1601.00661;
A. Ahmed et al, arXiv:1512.05771.

[24] A.E. Faraggi and J. Rizos, Nucl. Phys. B\textbf{895} (2015) 233.

[25] A.E. Faraggi and J. Rizos, Eur. Phys. Jour. C\textbf{76} (2016) 170.

[26] A. Karozas, S. F. King, G. K. Leontaris and A. K. Meadowcroft, “750 GeV diphoton excess from $E_6$ in F-theory GUTs,” Phys. Lett. B \textbf{757} (2016) 73.

[27] G. K. Leontaris and Q. Shafi, “Diphoton Resonance in F-theory inspired Flipped $SO(10)$”, arXiv:1603.06962 [hep-ph]

[28] K. Das, T. Li, S. Nandi and S. K. Rai, “A new proposal for diphoton resonance from $E_6$ motivated extra $U(1)$,” arXiv:1607.00810 [hep-ph].