750 GeV Diphoton excess from E_6 in F-theory GUTs

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Overview:

- LHC Results.
- $\mathcal{F}$-Theory model building.
- Diphoton from E_6 $\mathcal{F}$-GUT.
- Conclusions.

Athanasios Karozas, Stephen F. King, George K. Leontaris, Andrew K. Meadowcroft, 750 *GeV Diphoton excess from E6 in F-theory GUTs*, DOI: 10.1016/j.physletb.2016.03.054

based on:

J. C. Callaghan, S. F. King, G. K. Leontaris, J. High Energy Phys. 1309 (2013) 082 (*arXiv*:1307.4593).

▶LHC *Run* 2 *Data*

LHC Run II results

- *ATLAS* : 3.2 fb^{-1} of data, $M \approx 750$ GeV with 3.9σ, 14 events, $\Gamma \approx 45$ GeV ($\Gamma/M \approx 0.06$).

- *CMS* : 2.6 fb^{-1} of data, 10 $\gamma\gamma$ events, $M \approx 760$ GeV with 2.6σ, for $\Gamma/M \approx 0.06 \to 2.0\sigma$, $\sigma = 6fb$.

$$\sigma(pp \to \gamma\gamma) \approx \begin{cases} (0.5 \pm 0.6)fb & CMS & \sqrt{s} = 8\,TeV, \\ (0.4 \pm 0.8)fb & ATLAS & \sqrt{s} = 8\,TeV, \\ (6 \pm 3)fb & CMS & \sqrt{s} = 13\,TeV, \\ (10 \pm 3)fb & ATLAS & \sqrt{s} = 13\,TeV. \end{cases}$$

- Absence of $\gamma\gamma$ signals in *Run* 1 ($\sqrt{s} = 8$ TeV, 20.3 fb^{-1}).
Updates have discussed during the morning talks: Rob Mcpherson and K. Kousouris talk

"A statistical fluctuation" ?

or..

New physics BSM..?

A new boson

(L. D. Landau, Sov. Phys. Doklady 60, 207 (1948))
(C. N. Yang, Phys. Rev. 77, 242 (1950))

Theorem (*Yang-Landau*)

A massive spin-1 ($J = 1$) *particle cannot decay into a pair of identical massless spin-1 particles.*

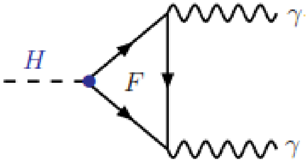
$$\Rightarrow J \neq 1$$

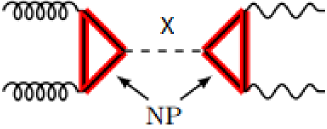
$$\Rightarrow J = 0 \qquad\qquad (J = 2 \quad graviton?)$$

- The new particle, X, could be interpreted as a *Scalar* ($X = S$) or *Pseudoscalar* ($X = A$).

A toy model

- *SM Higgs*, $H \to \gamma\gamma$ (see also G. Lazaridis talk)





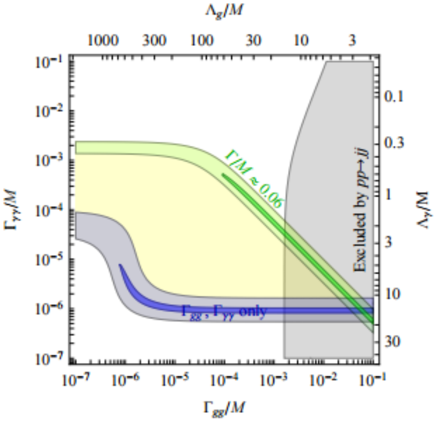
- gluon-gluon fusion mechanism: $gg \to X \to \gamma\gamma$.

$$\mathcal{L} \sim \lambda_f X \bar{f} f + m_f \bar{f} f + \frac{1}{2} m_X^2 X^2 + \cdots$$

- This interaction can be realised via *vector-like multiplets* f-$\bar{f}$,

$$\mathcal{L}_{eff} \propto -\frac{1}{4} S \left(g_{S\gamma} F_{\mu\nu} F^{\mu\nu} + g_{Sg} G_{\mu\nu} G^{\mu\nu} \right)$$

Franceschini et al. (1512.04933v2)



Region of $\Gamma_{\gamma\gamma}$ and Γ_{gg} in which the excess can be explained. The grey region is excluded by dijet searches at Run 1.

(See also N. Saoulidou and E. Tziaferi talk)

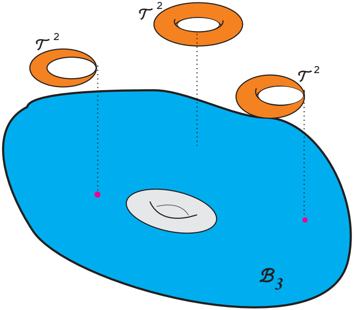
- $\mathcal{F}$-*theory* E_6 *GUTs*.

Based on:

James C. Callaghan, Stephen F. King, George K. Leontaris, J. High Energy Phys. 1309 (2013) 082 (*arXiv*:1307.4593).

What is $\mathcal{F}$-theory?

A powerful combination of Geometry and Brane dynamics! (C. Vafa 1996)
Total space : $(\mathcal{R}^{3,1} \times \chi)$ $\rightsquigarrow$ χ: *Elliptic Fibration*



CY 3-fold $\mathcal{B}_3$. *2-Torus*: $\tau = C_0 + i/g_s$

$\mathcal{F}$-theory and symmetries

▶The *fibration* can be described by the *Weierstrass equation*,

$$y^2 = x^3 + f(z)x + g(z).$$

▶The anomalies are classified in $\mathcal{ADE}$ *Lie Groups*. (*Kodaira* 1966)
▶The maximum symmetry enhancement is E_8,

$$E_8 \to \mathcal{G}_{GUT} \times \mathcal{G}_\perp$$

$$E_8 \supset E_6 \times SU(3)_\perp$$
$$E_8 \supset SO(10) \times SU(4)_\perp$$
$$E_8 \supset SU(5) \times SU(5)_\perp$$

We assume that compact manifold supports a divisor with E_6 $\Rightarrow$

E_6 GUTs

E_6 $\mathcal{F}$-theory model building

$$E_8 \rightarrow E_6 \times SU(3)_\perp,$$
$$248 \rightarrow (78,1) + (27,3) + (\overline{27},\bar{3}) + (1,8).$$

- *spectral cover*: $\mathcal{C}_3 = b_0 s^3 + b_2 s + b_3 \propto \prod_i^3 (s+t_i) = 0.$
- *Z_2 monodromy*: $t_1 \longleftrightarrow t_2$

$$\mathcal{C}_3 = (a_1 + a_2 s + a_3 s^2)(a_4 + a_5 s).$$

Matter	*Section*	*Homology*
$27_{t_{1,2}}$	a_1	$\eta - 2c_1 - \chi$
27_{t_3}	a_4	$\chi - c_1$

Flux Breaking

- E_6 breaking down to SM:

$$\begin{aligned} E_8 &\supset E_6 \times SU(3)_\perp \\ &\to SO(10) \times U(1)_\psi \times SU(3)_\perp \\ &\to SU(5) \times U(1)_\chi \times U(1)_\psi \times SU(3)_\perp \end{aligned}$$

- *Hypercharge Flux*:

$5, \bar{5}$	$10, \bar{10}$
$n(3,1)_{-1/3} - n(\bar{3},1)_{1/3} = M_5,$	$n(3,2)_{1/6} - n(\bar{3},2)_{-1/6} = M_{10},$
$n(1,2)_{1/2} - n(1,2)_{-1/2} = M_5 + N.$	$n(\bar{3},1)_{-2/3} - n(3,1)_{2/3} = M_{10} - N,$
	$n(1,1)_{1} - n(1,1)_{-1} = M_{10} + N.$

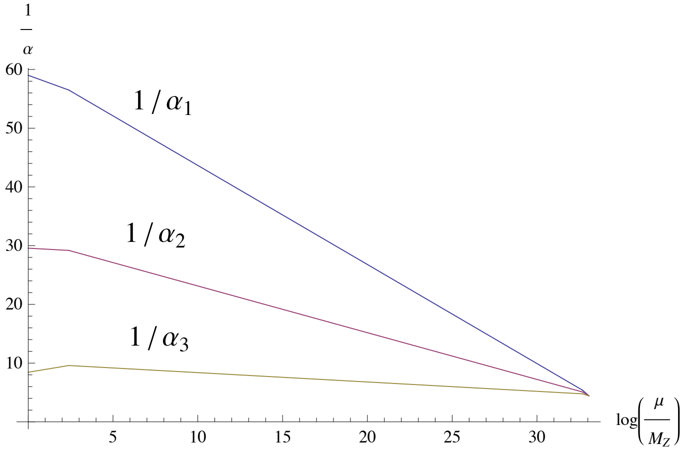
- Anomaly cancellation condition $\sum M_5 + \sum M_{10} = 0.$

Low Energy Spectrum

E_6	$SU(5)$	$TeVspectrum$	$\sqrt{10}Q_N$
27_{t_1}	$\overline{5}$	$3(d^c + L)$	1
27_{t_1}	10	$3(Q + u^c + e^c)$	$\frac{1}{2}$
27_{t_1}	5	$3D + 2H_u$	-1
27_{t_1}	$\overline{5}$	$3(\overline{D} + H_d)$	$-\frac{3}{2}$
27_{t_1}	1	θ_{14}	$\frac{5}{2}$
27_{t_3}	5	H_u	$-\frac{1}{2}$
27_{t_3}	1	$2\,\theta_{34}$	$\frac{5}{2}$
78	$\overline{5}$	$2\,X_{H_d} + X_{d^c}$	$-\frac{3}{2}$
78	5	$2\overline{X}_{\overline{H}_d} + \overline{X}_{\overline{d^c}}$	$\frac{3}{2}$
1	1	$\theta_{13}, \theta_{31}, \theta_0$	0

F-theory $\mathbf{E_6}$SSM-like model with TeV scale bulk exotics. The fields Q, u^c, d^c, L, e^c represent quark and lepton SM superfields in the usual notation. In this spectrum there are three families of H_u and H_d Higgs superfields, as compared to a single one in the MSSM. There are also three families of exotic D and $\overline{D}$ colour triplet superfields, where $\overline{D}$ has the same SM quantum numbers as d^c, and D has opposite quantum numbers. We have written the bulk exotics as X. The superfields θ_{ij} are SM singlets, with the two $\theta_{\mathbf{34}}$ singlets containing spin-0 candidates for the 750 GeV resonance.

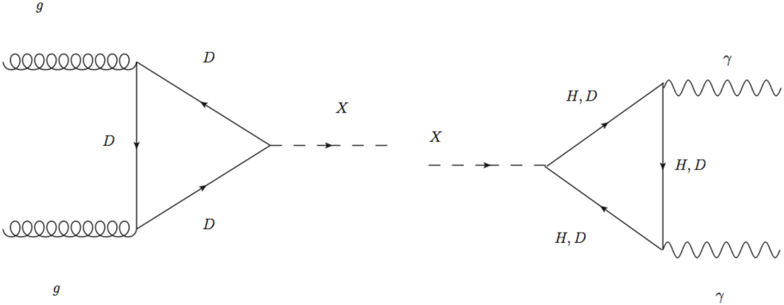
Unification



750 *GeV diphoton*

$$W \sim \lambda\theta_{14} H_d H_u + \lambda_{\alpha\beta\gamma}\theta^{\alpha}_{34} H^{\beta}_d H^{\gamma}_u + \kappa_{\alpha jk}\theta^{\alpha}_{34}\overline{D}_j D_k.$$

- We identify the 750 GeV scalar with one of the *singlets* θ_{34} .



$$\mathcal{L} \sim \kappa_i X \bar{D}_i D_i + \lambda_\alpha X H^\alpha_u H^\alpha_d + M_i \bar{D}_i D_i + M_{H_\alpha} H^\alpha_u H^\alpha_d + \frac{1}{2} M^2 X^2 + \cdots$$

Cross Section

▶ The cross section for $J = 0$ is : ($Franceschini\ et\ al.$ 1512.04933v1)

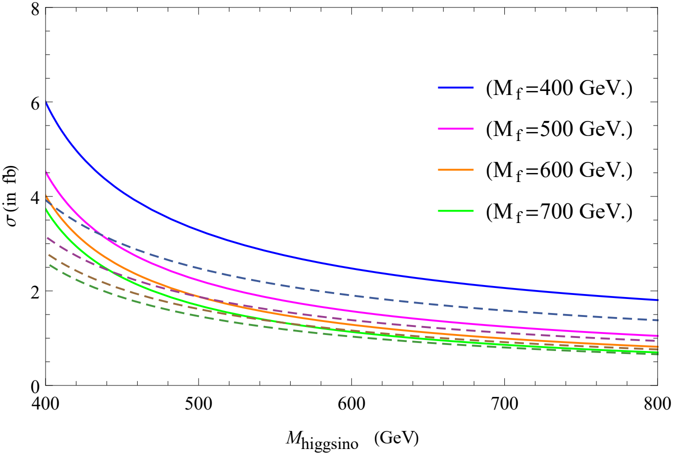
$$\sigma(pp \to X \to \gamma\gamma) = \frac{1}{M\Gamma s} C_{gg}\Gamma(X \to gg)\Gamma(X \to \gamma\gamma),$$

$$\frac{\Gamma(X \to gg)}{M} = \frac{\alpha_3^2}{2\pi^3}\left|\sum_i C_{r_i}\kappa_i \frac{2M_i}{M}\mathcal{X}\left(\frac{4M_i^2}{M^2}\right)\right|^2,$$

$$\frac{\Gamma(X \to \gamma\gamma)}{M} =$$

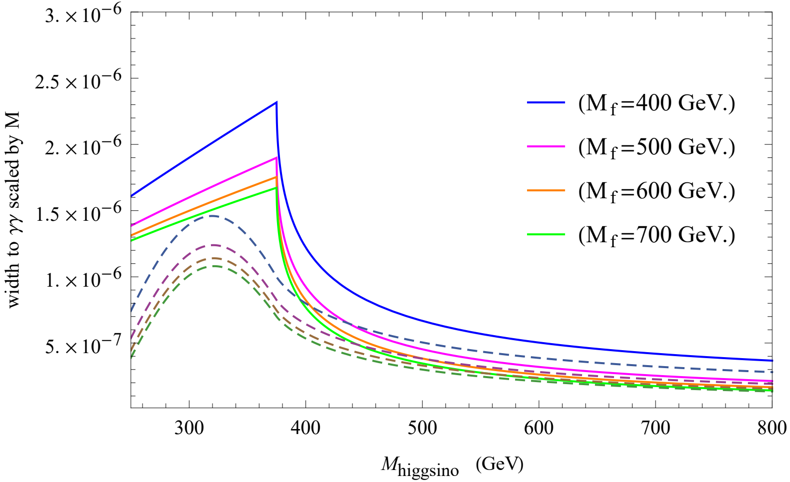
$$\frac{\alpha^2}{16\pi^3}\left|\sum_i d_{r_i} Q_i^2 \kappa_i \frac{2M_i}{M}\mathcal{X}\left(\frac{4M_i^2}{M^2}\right) + \sum_\alpha d_{r_\alpha} Q_\alpha^2 \lambda_\alpha \frac{2M_{H_\alpha}}{M}\mathcal{X}\left(\frac{4M_{H\alpha}^2}{M^2}\right)\right|^2.$$

Cross Section Results



Scalars (dashed) ,Pseudoscalars (solid), $M_i = M_f$, $y_f = 1$

$\Gamma(X \to \gamma\gamma)/M$



Scalars (dashed) ,*Pseudoscalars (solid)*, $M_i = M_f$, $y_f = \mathbf{1}$

Conclusions

- We have interpreted the 750 GeV diphoton resonance as one or more of the spinless components of two singlet superfields arising from the three 27 of E_6 in F-theory.
- In order to obtain large enough results, we require the resonance to be identified with one of the two pseudoscalar states.
- A sufficiently large cross section requires quite light color triplets and charge Higgsinos below a TeV.
- The smoking gun prediction of the model is the existence of other similar spinless resonances, possibly close in mass to 750-760 GeV. There are also bulk singlets arising from the 78 reps of the model which are candidates for the 750 GeV diphoton resonance.

References

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[5]. J. C. Callaghan, S. F. King, G. K. Leontaris, J. High Energy Phys. 1309 (2013) 082 (*arXiv*:1307.4593).
[6]. A. Karozas, S. F. King, G. K. Leontaris, A. K. Meadowcroft, 750 *GeV Diphoton excess from E6 in F-theory GUTs*, DOI: 10.1016/j.physletb.2016.03.054

back up

Triangular-loop functions

The function $\mathcal{X}(t)$ takes a different form, depending on whether the particle is a scalar or a pseudoscalar - $\mathcal{S}$ or $\mathcal{P}$ respectively:

$$\mathcal{P}(t) = \arctan^2(1/\sqrt{t-1}), \quad (1)$$

$$\mathcal{S}(t) = 1 + (1-t)\mathcal{P}(t)\,. \quad (2)$$

In the case in question with colour triplets of mass M_i mediating the process, $Q_i = 1/3$, $C_{r_i} = 1/2$, and $d_{r_i} = 3$, while the Higgsinos have $Q_i = d_{r_i} = 1$ and a mass of M_k.