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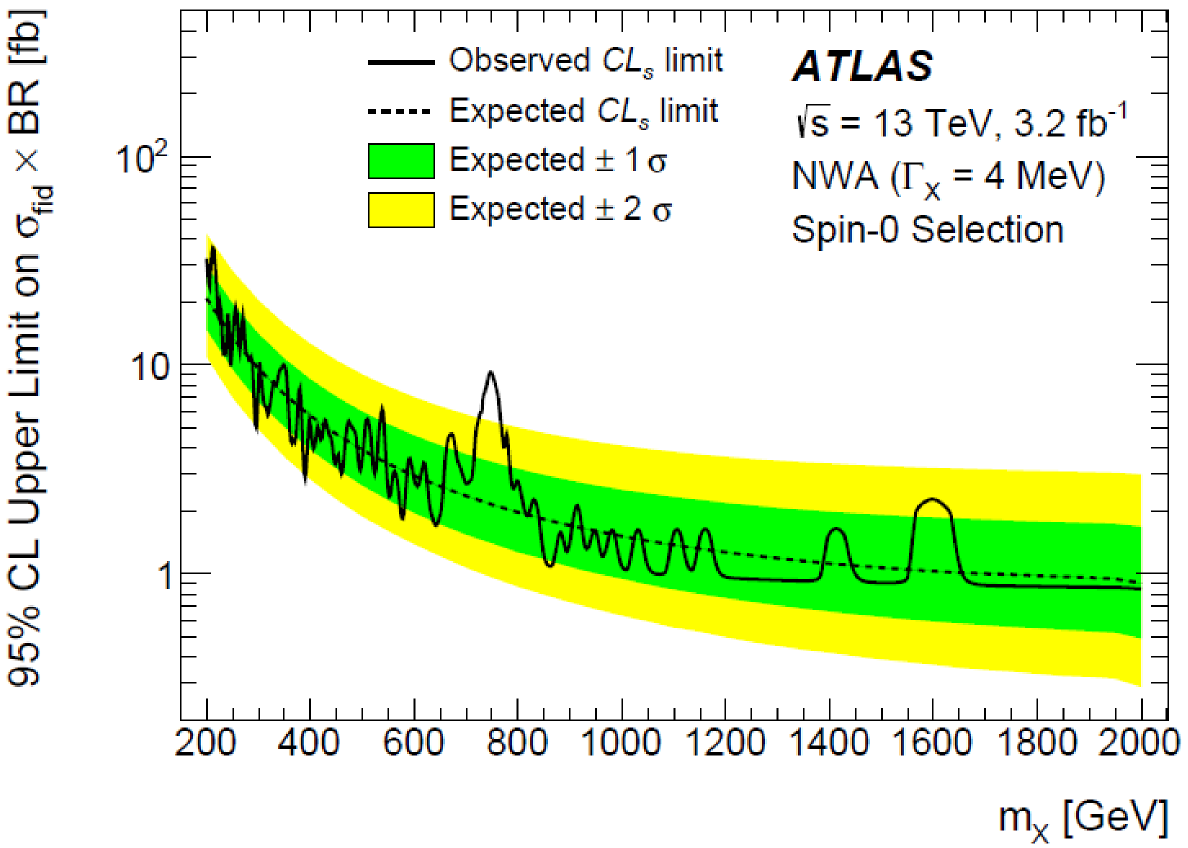
Stringy Explanation for the 750 GeV diphoton excess and the b-> s l+ l- anomalies

Christos Kokorelis

• 750 GeV diphoton excess



deviation from the background is observed at a diphoton invariant mass around 750 GeV (from ---> CMS + ATLAS)

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$$\sigma(pp \to \gamma\gamma) \approx \begin{cases} (0.5 \pm 0.6)\,\text{fb} & \text{CMS [2]} & \sqrt{s} = 8\,\text{TeV}, \\ (0.4 \pm 0.8)\,\text{fb} & \text{ATLAS [3]} & \sqrt{s} = 8\,\text{TeV}, \\ (6 \pm 3)\,\text{fb} & \text{CMS [1]} & \sqrt{s} = 13\,\text{TeV}, \\ (10 \pm 3)\,\text{fb} & \text{ATLAS [1]} & \sqrt{s} = 13\,\text{TeV}. \end{cases}$$

$$\sigma(pp \to S \to \gamma\gamma) = \frac{2J+1}{M\Gamma s}\left[\sum_{\wp} C_{\wp\bar{\wp}}\Gamma(S \to \wp\bar{\wp})\right]\Gamma(S \to \gamma\gamma)$$

$$\wp = \{g, b, c, s, u, d, \gamma\}$$

$$\begin{aligned} C_{gg} &= \frac{\pi^2}{8}\int_{M^2/s}^{1}\frac{dx}{x}g(x)g(\frac{M^2}{sx}), \\ C_{\gamma\gamma} &= 8\pi^2\int_{M^2/s}^{1}\frac{dx}{x}\gamma(x)\gamma(\frac{M^2}{sx}), \\ C_{q\bar{q}} &= \frac{4\pi^2}{9}\int_{M^2/s}^{1}\frac{dx}{x}\left[q(x)\bar{q}(\frac{M^2}{sx}) + \bar{q}(x)q(\frac{M^2}{sx})\right] \end{aligned}$$

• 750 GeV diphoton excess

$$r = \sigma_{13\,\mathrm{TeV}} / \sigma_{8\,\mathrm{TeV}} = [C_{\wp\wp}/s]_{13\,\mathrm{TeV}} / [C_{\wp\wp}/s]_{8\,\mathrm{TeV}}$$

For gluon fusion r ~ 4.7

$$\sigma(gg \to X \to \gamma\gamma) = \frac{1}{M_X \cdot \Gamma \cdot s} C_{gg} \Gamma(X \to gg) \Gamma(X \to \gamma\gamma)$$

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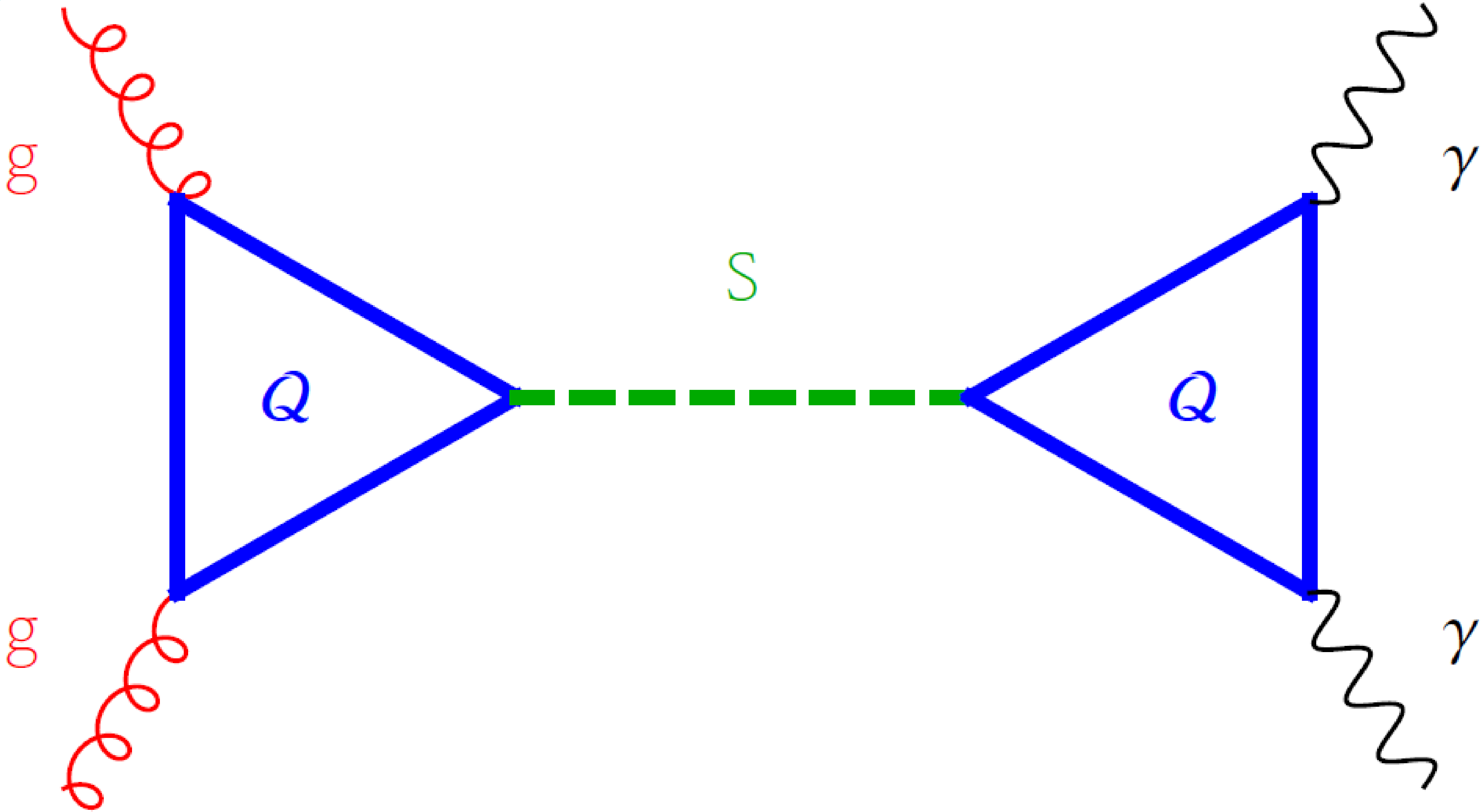

What is the γγ resonance at 750 GeV?
hep-ph/1512.04933

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SM extended by adding one (or more) scalar singlets S + extra vector-like fermions Qf & scalars Qs

$$S\bar{Q}_f(y_f + i\, y_{5f}\gamma_5)Q_f + S A_s \tilde{Q}_s^* \tilde{Q}_s$$

The partial decay widths from loops involing fermions or scalars are given by

$$\frac{\Gamma(X \to gg)}{M_X} = \frac{\alpha_3^2}{2\pi^3}\left|\sum_f C_{r_f}\sqrt{\tau_f}\lambda_f S(\tau_f) + \sum_s C_{r_s}\frac{A_s}{2M_X}P(\tau_s)\right|^2$$

$$\frac{\Gamma(X \to \gamma\gamma)}{M_X} = \frac{\alpha^2}{16\pi^3}\left|\sum_f d_{r_f} q_f^2\sqrt{\tau_f}\lambda_f S(\tau_f) + \sum_s d_{r_s} q_s^2\frac{A_s}{2M_X}P(\tau_s)\right|^2$$

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$$\sigma(pp \to \gamma\gamma) \approx 8\,\text{fb at } \sqrt{s} = 13\,\text{TeV}$$

$$\Gamma = \Gamma_{gg} + \Gamma_{\gamma\gamma}$$

$$\Gamma_{\gamma\gamma} \equiv \Gamma(S \to \gamma\gamma) \qquad \Gamma_{gg} \equiv \Gamma(S \to gg)$$

When production from $\gamma\gamma$ partons can be neglected

$$\frac{\Gamma_{\gamma\gamma}}{M}\frac{\Gamma_{gg}}{M} \approx 1.1 \times 10^{-6}\ \frac{\Gamma}{M} \approx 6 \times 10^{-8}$$

$$\Gamma/M \approx 0.06$$

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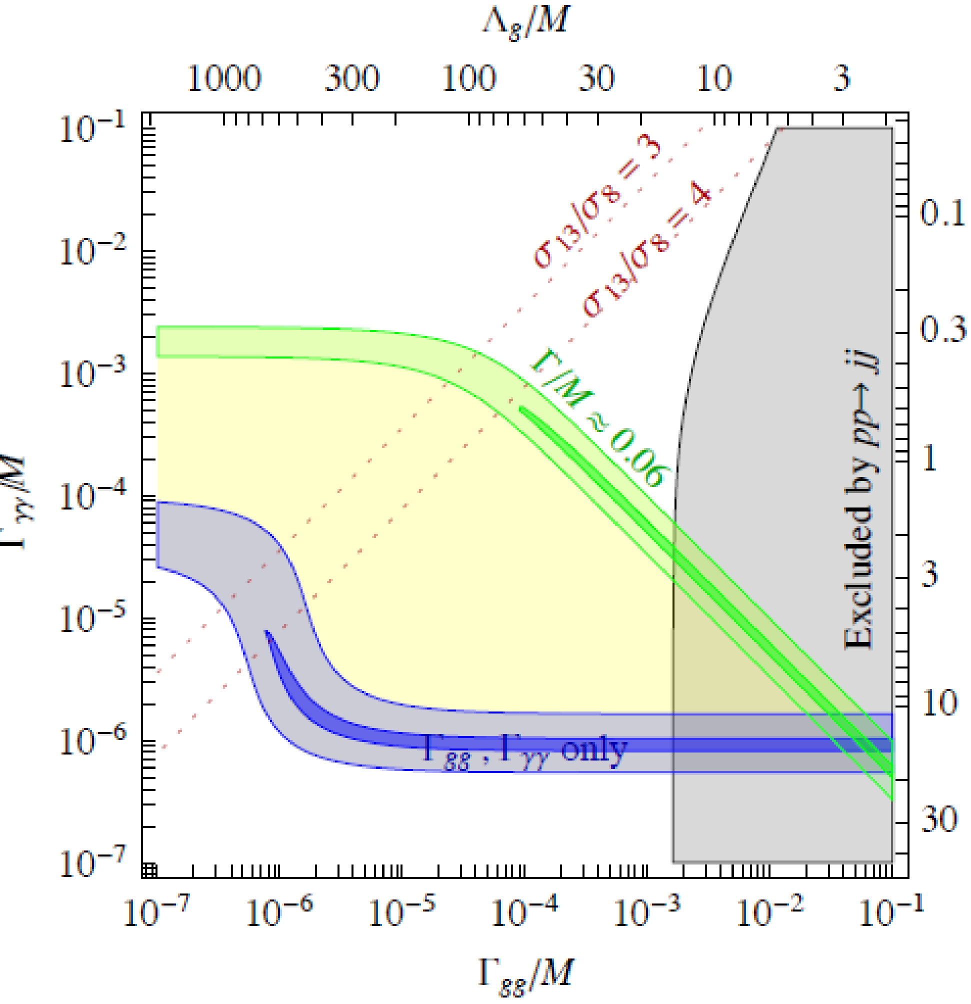
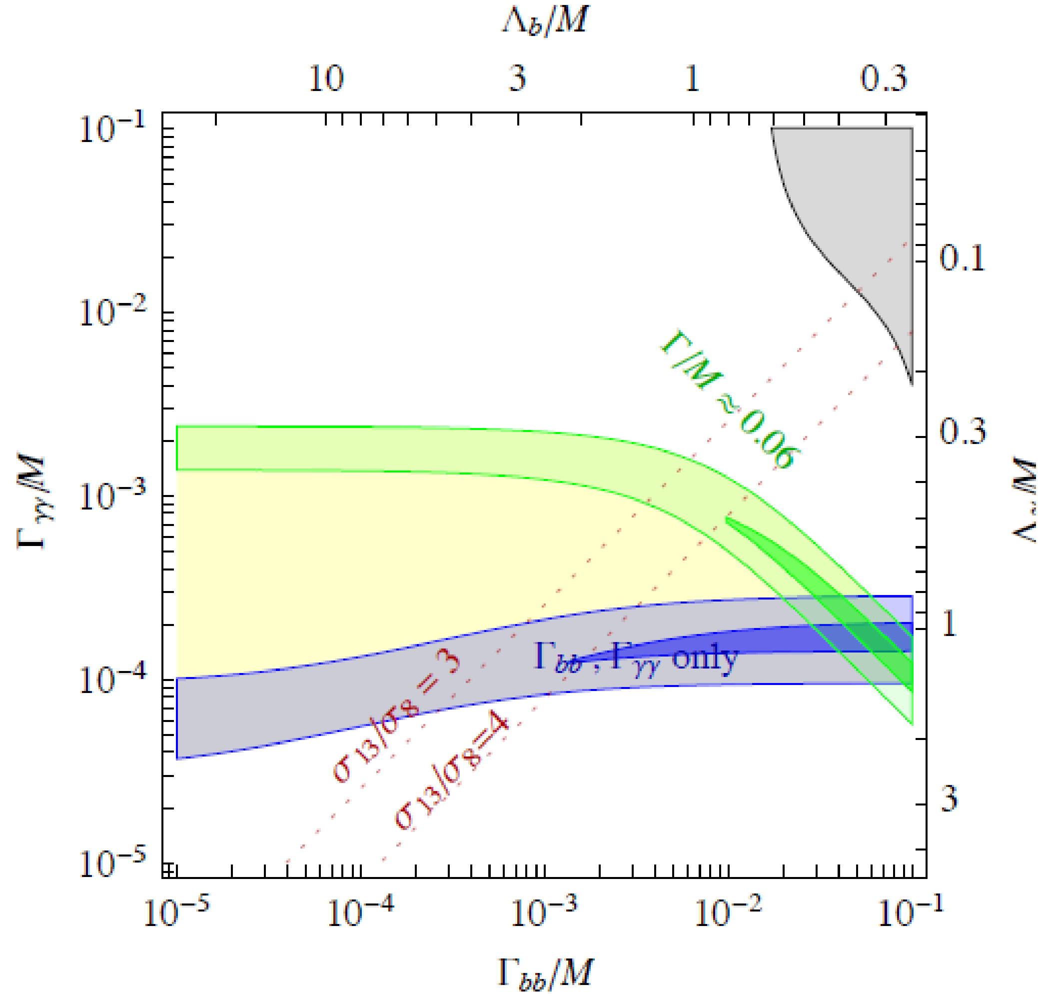
• 750 GeV diphoton excess





$\Gamma(S \to \gamma\gamma)/M \approx \text{few} \times 10^{-6}$ $\Gamma(S \to gg)/M \approx \text{few} \times 10^{-3}\text{–}10^{-6}$

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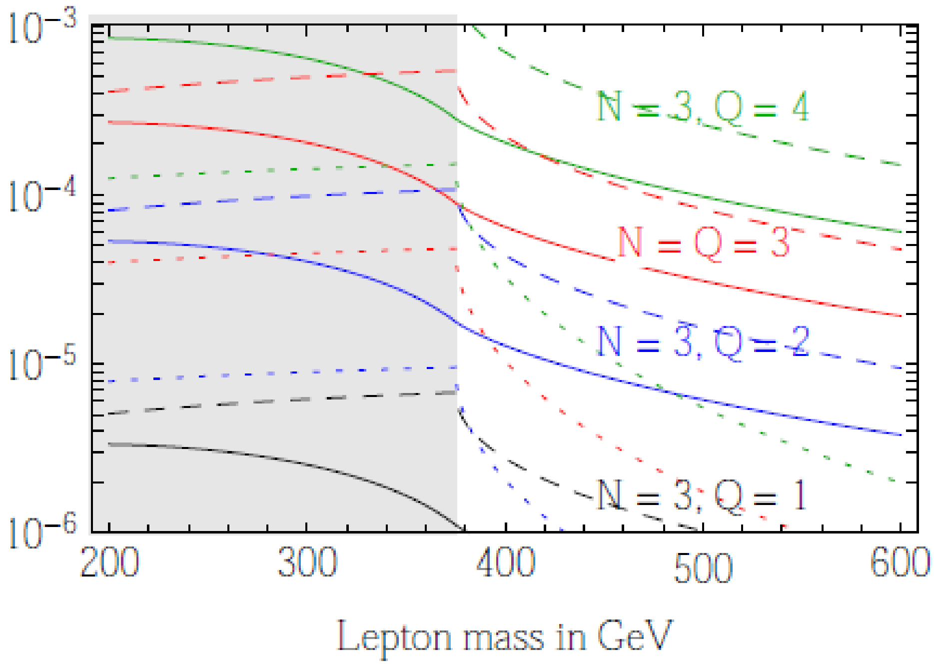
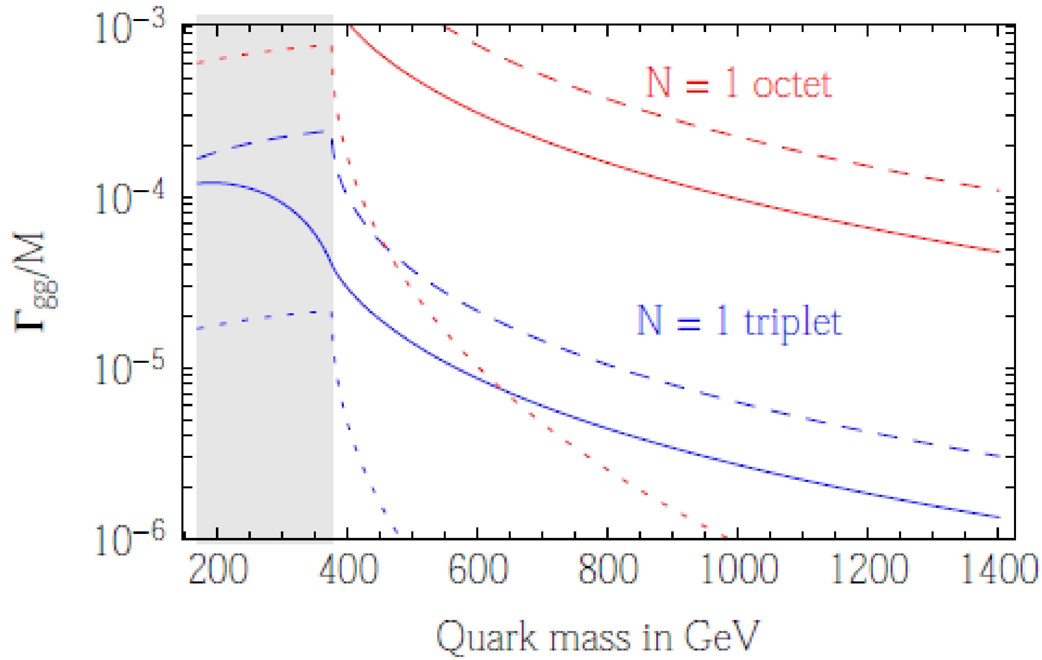
• 750 GeV diphoton excess

Scalar (continuous), pseudo−scalar (dashed) and cubic coupling $y, y_5 = 1$, $A = M$





hep-ph/1512.04933

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Explaining the 750 diphoton excess using model building from superstrings :

L.A.Anchordoqui, I.Antoniadis, H.Goldberg, X.Huang, D.Lust and T.R.Taylor
L.E.Ibanez and V.Martin-Lozano;
M.Cvetic, M.Halverson and P.Langacker;
G.K.Leontaris and Q.Shafi;
M.Bianchi and P.Anastasopoulos;
M.C.Romao, A.Karozas, S.F.King, G.K.Leontaris,
A.K.Meadowcroft; A.E.Faraggi and J.Rizos;
J.Asfaque, L.D.Rose, A.E.Faraggi, C.Marzo

or otherwise G. Lazarides and Q.Shafi

It is possible for the **750 GeV diphoton excess** to be explained using **D-brane models**
e.g. using **D6-branes intersecting at angles**
C.K, to appear

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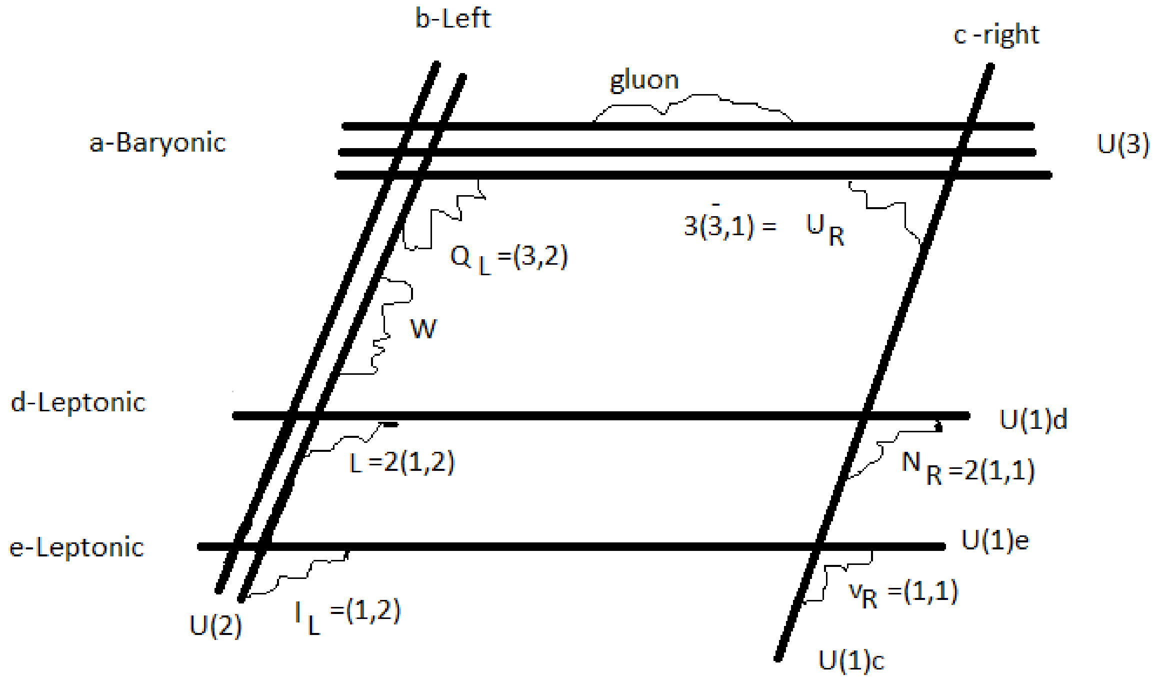
- C.K, New Standard Model Vacua from Intersecting Branes, hep-th/0205147



5-stacks of D6-branes intersecting at angles, SM at low energy
U(1)y= (1/6)U(1)_a – (1/2) U(1)_c - (1/2)U(1)_d - (1/2) U(1)_e
***** --->> BARYON & LEPTON number is conserved**

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Matter Fields		Intersection	Q_a	Q_b	Q_c	Q_d	Q_e	Y
Q_L	$(3, 2)$	$I_{ab} = 1$	1	-1	0	0	0	$1/6$
q_L	$2(3, 2)$	$I_{ab^*} = 2$	1	1	0	0	0	$1/6$
U_R	$3(\bar{3}, 1)$	$I_{ac} = -3$	-1	0	1	0	0	$-2/3$
D_R	$3(\bar{3}, 1)$	$I_{ac^*} = -3$	-1	0	-1	0	0	$1/3$
L	$2(1, 2)$	$I_{bd} = -2$	0	-1	0	1	0	$-1/2$
l_L	$(1, 2)$	$I_{be} = -1$	0	-1	0	0	1	$-1/2$
N_R	$2(1, 1)$	$I_{cd} = 2$	0	0	1	-1	0	0
E_R	$2(1, 1)$	$I_{cd^*} = -2$	0	0	-1	-1	0	1
ν_R	$(1, 1)$	$I_{ce} = 1$	0	0	1	0	-1	0
e_R	$(1, 1)$	$I_{ce^*} = -1$	0	0	-1	0	-1	1

Table 1: Low energy fermionic spectrum of the five stack string scale $SU(3)_C \otimes SU(2)_L \otimes U(1)_a \otimes U(1)_b \otimes U(1)_c \otimes U(1)_d \otimes U(1)_e$, type I D6-brane model together with its $U(1)$ charges. Note that at low energies only the SM gauge group $SU(3) \otimes SU(2)_L \otimes U(1)_Y$ survives.

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Tadpole conditions of the ultraviolet complete theory <-> cancellation of cubic gauge anomalies to low energy

$$\frac{9n_a^2}{\beta^1} + 2\frac{n_b^1}{\beta^2} + \frac{n_d^2}{\beta^1} + \frac{n_e^2}{\beta^1} + N_D\frac{2}{\beta^1\beta^2} = 16$$

N_i	(n_i^1, m_i^1)	(n_i^2, m_i^2)	(n_i^3, m_i^3)
$N_a = 3$	$(1/\beta^1, 0)$	$(n_a^2, \epsilon\beta^2)$	$(3, \tilde{\epsilon}/2)$
$N_b = 2$	$(n_b^1, -\epsilon\beta^1)$	$(1/\beta^2, 0)$	$(\tilde{\epsilon}, 1/2)$
$N_c = 1$	$(n_c^1, \epsilon\beta^1)$	$(1/\beta^2, 0)$	$(0, 1)$
$N_d = 1$	$(1/\beta^1, 0)$	$(n_d^2, 2\epsilon\beta^2)$	$(1, -\tilde{\epsilon}/2)$
$N_e = 1$	$(1/\beta^1, 0)$	$(n_e^2, \epsilon\beta^2)$	$(1, -\tilde{\epsilon}/2)$

Table 2: Tadpole solutions of D6-branes wrapping numbers giving rise to the standard model gauge group and spectrum at low energies. The solutions depend on five integer parameters, n_a^2, n_d^2, n_e^2, n_b^1, n_c^1, the NS-background β^i and the phase parameters $\epsilon = \pm 1$, $\tilde{\epsilon} = \pm 1$.

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The Yukawa couplings in this model follow the usual pattern that appears in intersecting branes [10]. The couplings between the two fermion states F_L^i, $\bar{F}_R^j$ and the Higgs fields H^k, arise from the stretching of the worldsheet between the three D6-branes which cross at those intersections. For a six dimensional torus they can take the following form in the leading order [10],

$$Y^{klm} = e^{-\tilde{A}_{klm}}, \tag{6.1}$$

where $\tilde{A}_{klm}$ is the worldsheet area connecting the three vertices in the six dimensional space. The areas of each of the two dimensional torus involved in this interaction is typically of order one in string units. For the models discussed in table (1), the Yukawa interactions for the chiral spectrum of the SM's yield:

$$\begin{aligned} Y_j^U Q_L U_R^j h_1 + Y_j^D Q_L D_R^j H_2 \quad &+ \\ Y_{ij}^u q_L^i U_R^j H_1 + Y_{ij}^d q_L^i D_R^j h_2 &+ \\ Y_h^l \, l_L^h \, \nu_R^h \, h_1 + \; Y_h^e l_L^h e_R^h H_2 \quad &+ \\ Y_{ij}^N L^i N_R^j h_1 + Y_{ij}^E L_i E_R^j H_2 + \; h.c \end{aligned} \tag{6.2}$$

The model exhibits a 2 Higgs system ....as the MSSM

• 5-stack D-brane model intersecting D6-branes

Neutrinos ~ 0.1-10 eV <-> < 1 < Ms < 10 TeV

$$\alpha'(LN_R)\ (Q_L U_R)^{\star},\ \ \alpha'(l\nu_R)(q_L U_R)$$

$$\frac{< u_R u_L >}{M_s^2} = \frac{(240MeV)^3}{M_s^2}$$

u-quark chiral condensate

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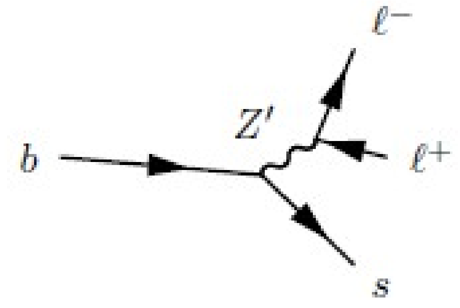
Recently it was shown (hep-ph/1512.02218) that this model offers a **“stringy explanation of b-> s l+l_ anomalies”**

Stringy explanation of $b \to s\ell^+\ell^-$ anomalies

Alejandro Celis[a], Wan-Zhe Feng[a,b] and Dieter Lüst[a,b*]

We show that the recent anomalies in $b \to s\ell^+\ell^-$ transitions observed by the LHCb collaboration can be accommodated within string motivated models with a low mass Z' gauge boson. Such Z' gauge boson can be obtained in compactifications with a low string scale. We consider a class of intersecting D-brane models in which different families of quarks and leptons are simultaneously realized at different D-brane intersections. The explanation of $b \to s\ell^+\ell^-$ anomalies via a stringy Z' sets important restrictions on these viable D-brane constructions.

“The b-> s l+ l+ decay”



Note the extra Z'

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Current data for $b \to s\ell^+\ell^-$ decays shows a series of deviations from the Standard Model (SM) [1–3]. Among the relevant observables, the ratio R_K measuring the $B^+ \to K^+\mu^+\mu^-$ rate normalized by the electron mode is particularly interesting since it is known within the SM with a very good accuracy and constitutes a test of lepton universality in B-meson decays [4]. This ratio has been measured recently by the LHCb collaboration in the q^2-range $1 < q^2 < 6$ GeV^2 giving $R_K = 0.745^{+0.090}_{-0.074} \pm 0.036$, representing a 2.6σ deviation from the SM prediction $R_K \simeq 1$ [3]. The measurement of the observable P_5' in $B^0 \to K^*\mu^+\mu^-$ decays shows a tension with respect to the SM at the 3.7σ level [1, 5]. Additionally, the differential branching fraction $B_s \to \phi\mu^+\mu^-$ was recently reported to be 3.5σ below the SM prediction in the low-q^2 region [2].

A massive Z' boson of mass of $\mathcal{O}(10)$ TeV is a possible new physics candidate to explain the observed $b \to s\ell^+\ell^-$ anomalies [6–21], see Figure 1. A neutral boson at the TeV scale can evade current limits from the LHC while potentially produce the relevant deviations from the SM in $b \to s\ell^+\ell^-$ transitions if the following conditions are met:

- Flavor changing $Z'_\alpha \bar{s}_L \gamma^\alpha b_L$ couplings are present at tree-level.
- The Z' boson couples differently to muons and electrons in order to accommodate R_K.

A. Celis, Wan-Zhe Feng, D. Lust, hep-ph/1512.02218

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2.1 $b \to s\ell^+\ell^-$ anomalies

New physics contributions to semi-leptonic $b \to s\ell^+\ell^-$ decays are described in a model-independent manner using the effective weak Hamiltonian [38]

$$\mathcal{H}_{\text{eff}} \supset -\frac{4G_F}{\sqrt{2}}\frac{\alpha}{4\pi}V_{ts}^*V_{tb}\sum_i \left[C_i^\ell(\mu)Q_i^\ell(\mu) + C_i'^\ell(\mu)Q_i'^\ell(\mu)\right] . \tag{1}$$

We focus here on the operators

$$\begin{aligned} Q_9^\ell &= (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu \ell)\,, \qquad & Q_{10}^\ell &= (\bar{s}\gamma_\mu P_L b)(\bar{\ell}\gamma^\mu\gamma_5 \ell)\,, \\ Q_9'^\ell &= (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu \ell)\,, \qquad & Q_{10}'^\ell &= (\bar{s}\gamma_\mu P_R b)(\bar{\ell}\gamma^\mu\gamma_5 \ell)\,. \end{aligned} \tag{2}$$

In the SM the Wilson coefficients are $C_9^{\text{SM}\ell} \simeq -C_{10}^{\text{SM}\ell} \simeq 4.2$ at the m_b scale, while $C_{9,10}'^\ell \simeq 0$. We write in the following $C_i^\ell = C_i^{\text{SM}\ell} + C_i^{\text{NP}\ell}$.

Global fits of the Wilson coefficients to the available $b \to s\ell^+\ell^-$ data have been performed by different groups, with varying statistical methods and treatments of hadronic uncertainties [39–47]. Notably, the observed pattern of deviations in $b \to s\ell^+\ell^-$ transitions seems to hint towards a consistent interpretation in terms of new physics. Current data favors new physics contribution in $C_9^{\text{NP}\mu}$ of size $C_9^{\text{NP}\mu} \sim -1$ [39, 41–45]. The reported significance of this scenario varies within the different analyses available, a recent comprehensive study quotes a significance of $\sim 4\sigma$ [39].

A. Celis, Wan-Zhe Feng, D. Lust,
hep-ph/1512.02218

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5-stack D-brane model predicts ->

$C_9^{NP\mu}=C_9^{NPe}$,

$-0.8 < C_{10}^{NPe} < -0.3$,

$C_{10}^{NP\mu} \to 0$,

$3.5 < m_{Z'} < 5.5$ TeV

&

$Br(Z'\to\mu^+\mu^-)/Br(Z'\to e^+e^-) \sim [0.5, 0.9]$

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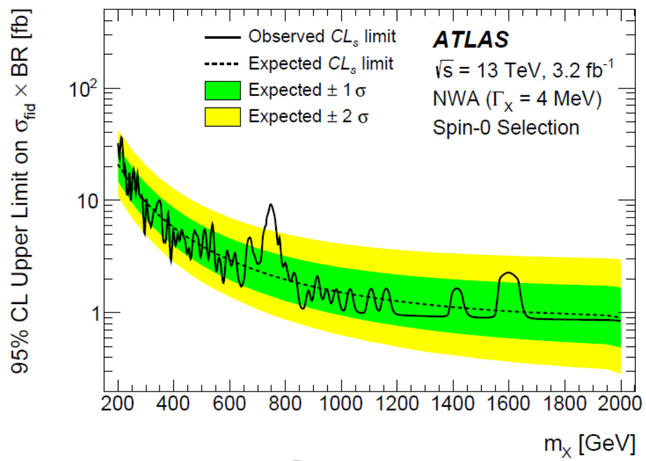
The word "Theory" comes from the Greek word "θεωρία"(pronounced theoria) which is made from 2 words : Θεός/God (pronounced theos -> present Greek language dictionary) & ορώ/see (pronounced oro -> ancient Greek word).
Theory = θεός + ορώ = see+God -> I "see" the God ..!!
However, the experiment



may be the final judge of all the different prediction of the Theorists...