# Composite Models for the 750 GeV Diphoton Excess

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# Lattice & BSM

- Nuclear / strong interaction properties
  - — Flavor physics
  - — Dark matter detection
  - — Proton decay
  - — QCD axion
  - — …
- TeV scale physics
  - — Technicolor
  - — Composite Higgs
  - — Dark sector (in varying scales)
  - — …
- Formal aspects
  - — Gauge theory phases (conformality)
  - — Quantum gravity (matrix models)
  - — …

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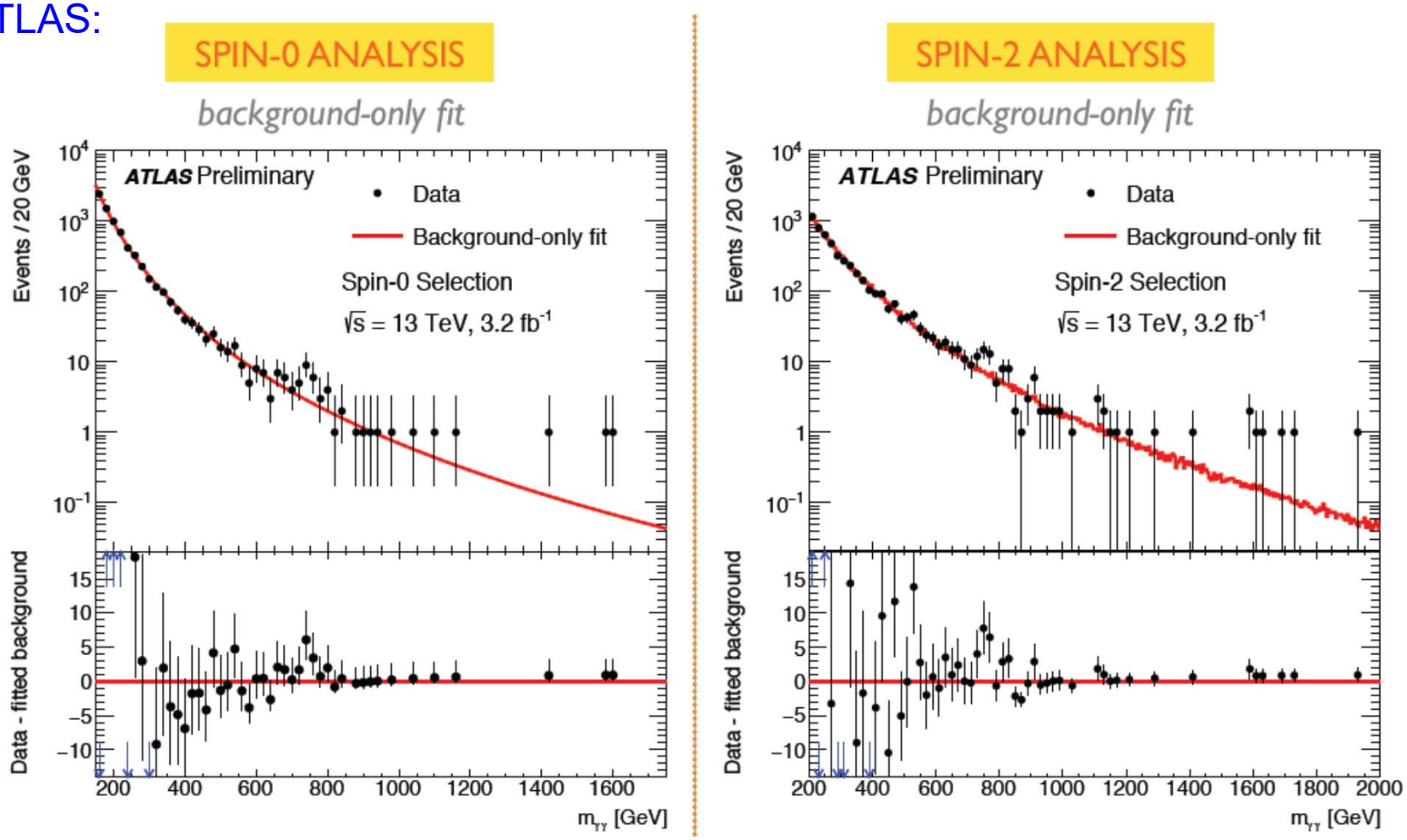
# The 750 GeV diphoton excess

Diphoton search — (relatively) clean signal

ATLAS:



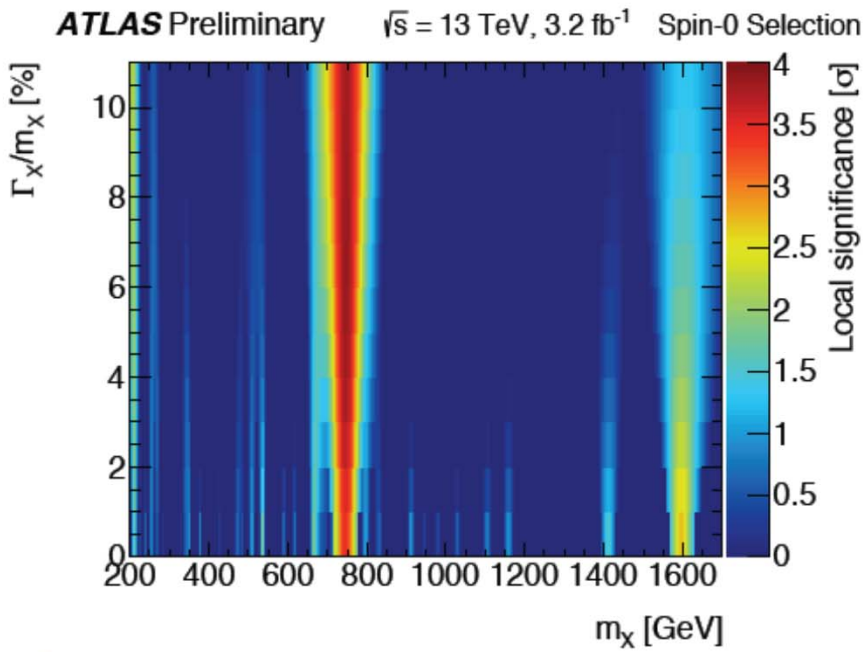

$E_T^{\gamma 1} > 0.4\ m_{\gamma\gamma}$, $E_T^{\gamma 2} > 0.3\ m_{\gamma\gamma}$

$E_T^{\gamma 1} > 55$ GeV, $E_T^{\gamma 2} > 55$ GeV

Delmastro at Moriond EW 2016

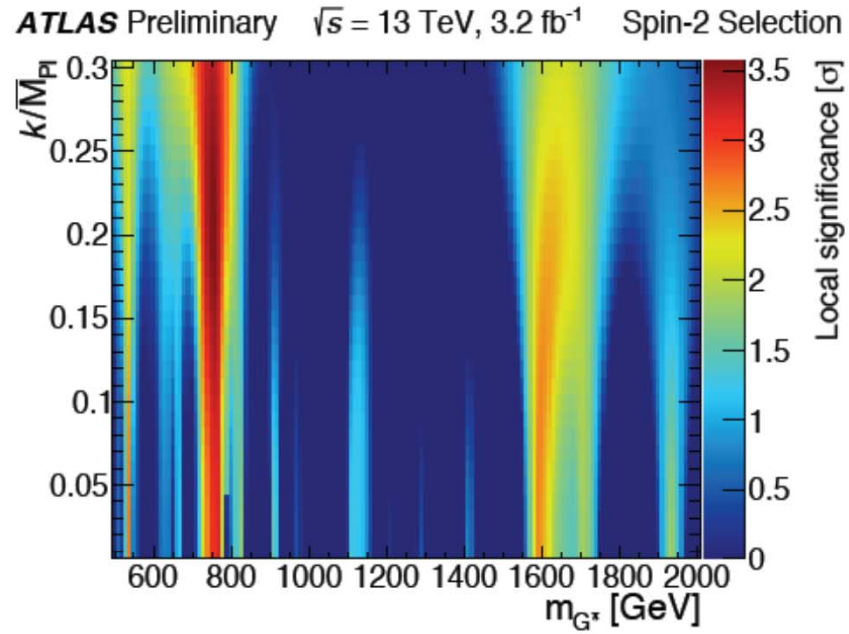
## ATLAS (continued):

### SPIN-0 ANALYSIS




- Largest deviation from B-only hypothesis
  - ✓ $m_X$ ~ 750 GeV, $\Gamma_X$ ~ 45 GeV (6%)
  - ✓ Local Z = **3.9 σ**
  - ✓ Global Z = **2.0 σ**

### SPIN-2 ANALYSIS




- Largest deviation from B-only hypothesis
  - ✓ $m_G$ ~ 750 GeV, $\kappa/M_{Pl}$ ~ 0.2 ($\Gamma_G$ ~ 7% $m_G$)
  - ✓ Local Z = **3.6 σ**
  - ✓ Global Z = **1.8 σ**

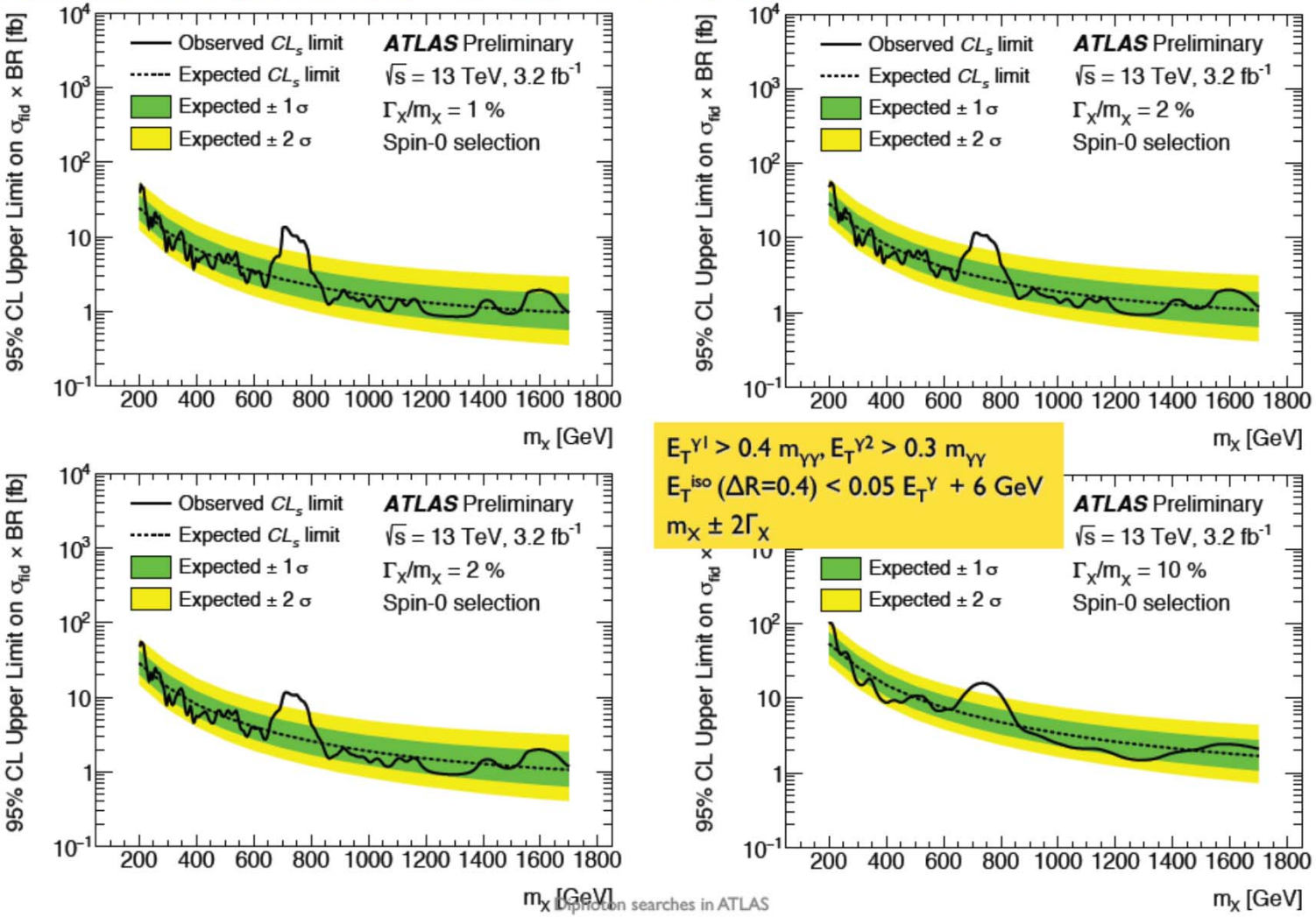
… A peak ~ 750 GeV

slight preference to a wide width, but not significant (see next)

ATLAS (continued):

# Limit on fiducial cross-section

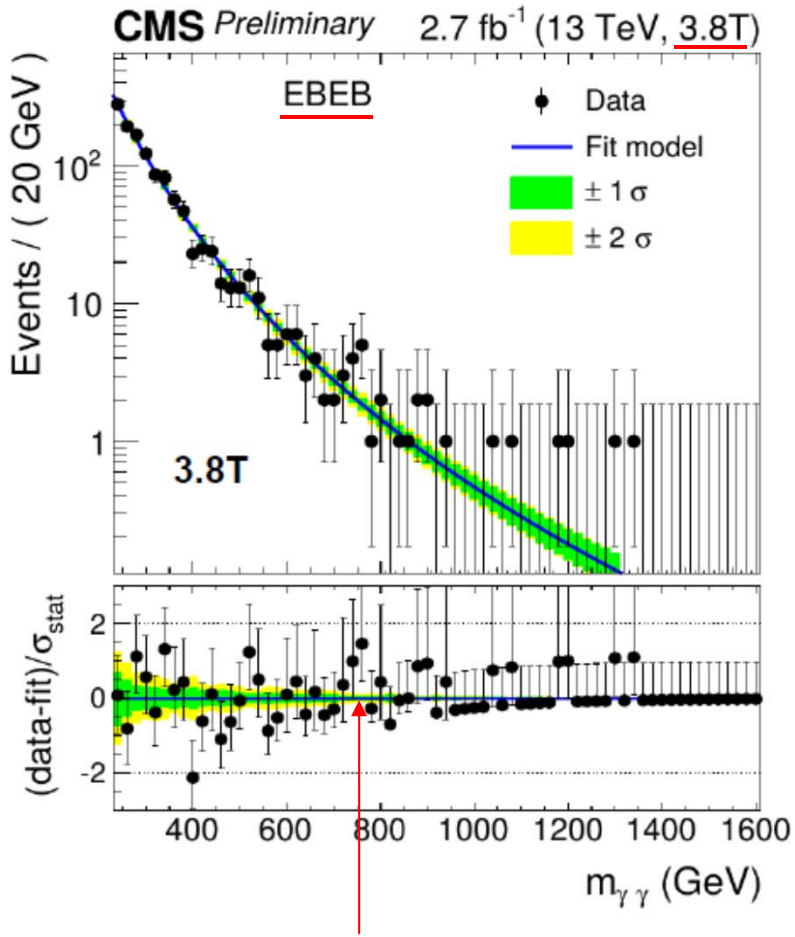
SPIN-0 ANALYSIS

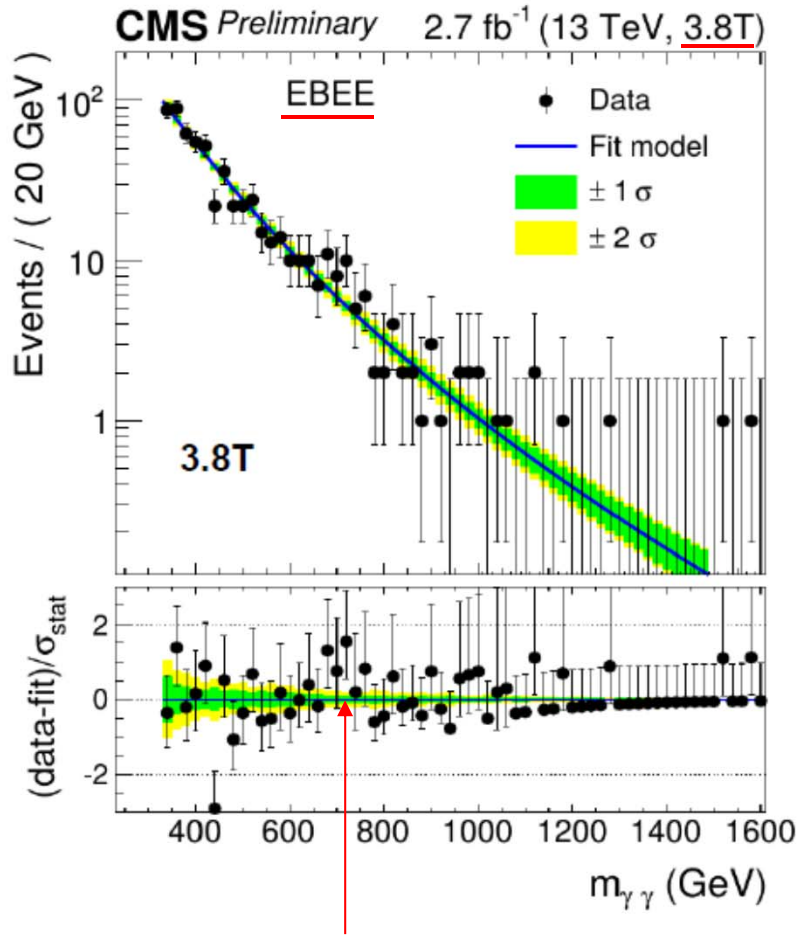



… A narrow width is perfectly consistent

# What about CMS?

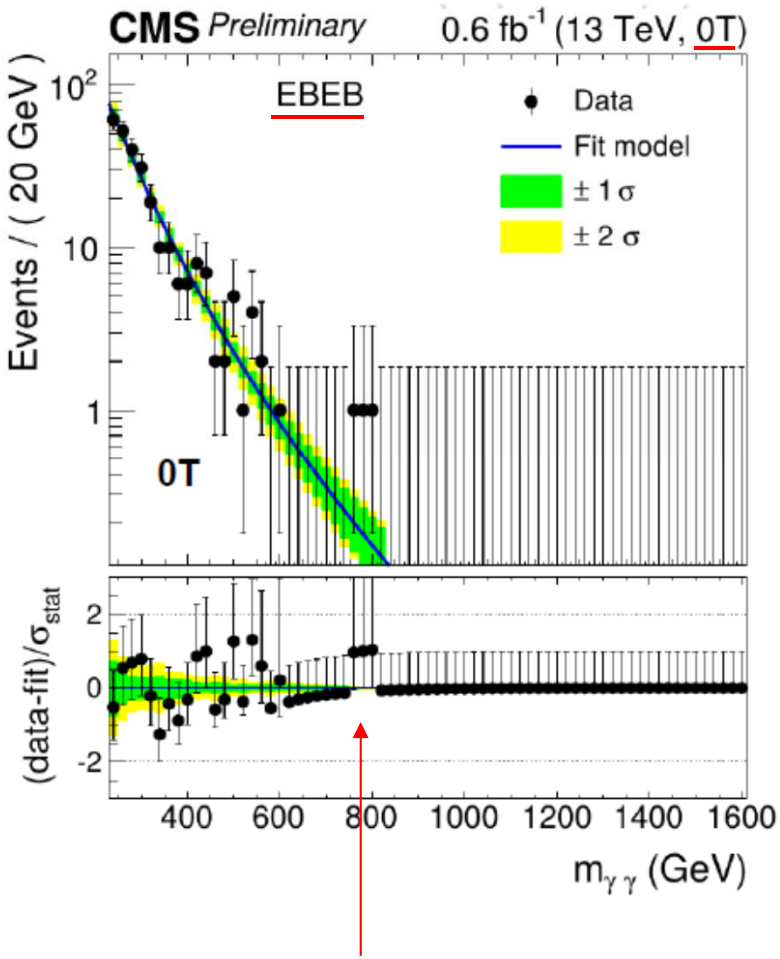
CMS:

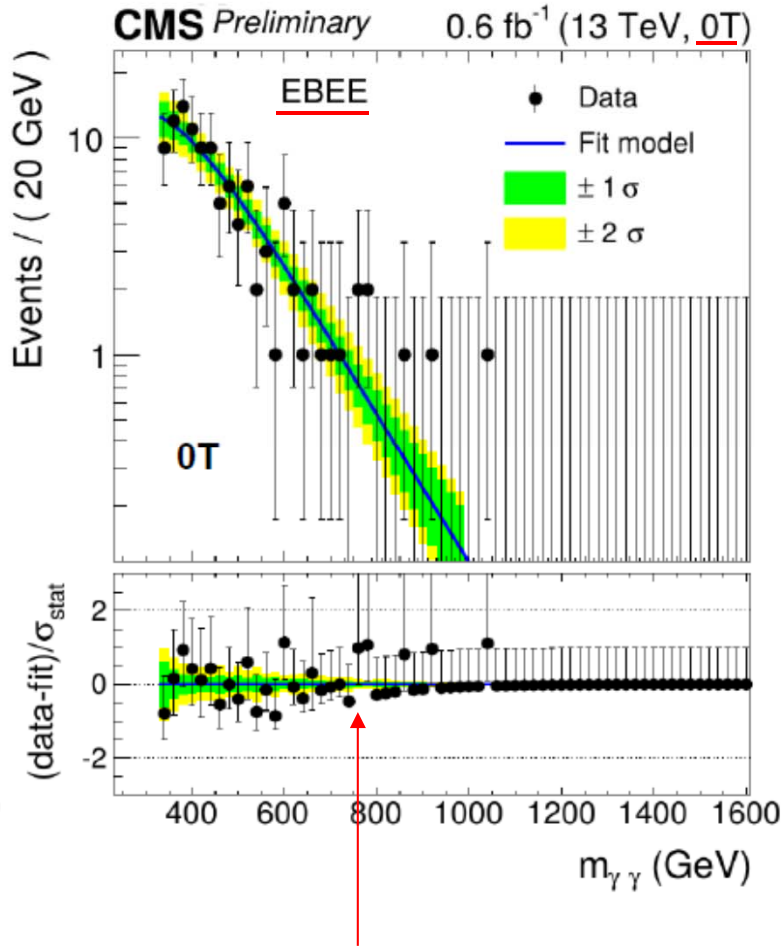



Musella at Moriond EW 2016

CMS (continued):

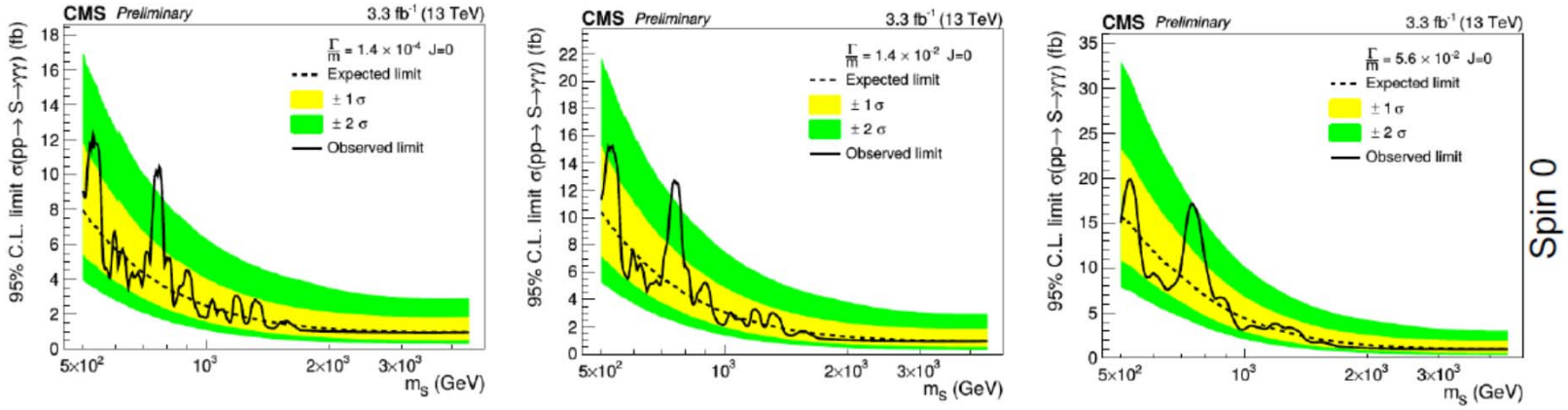


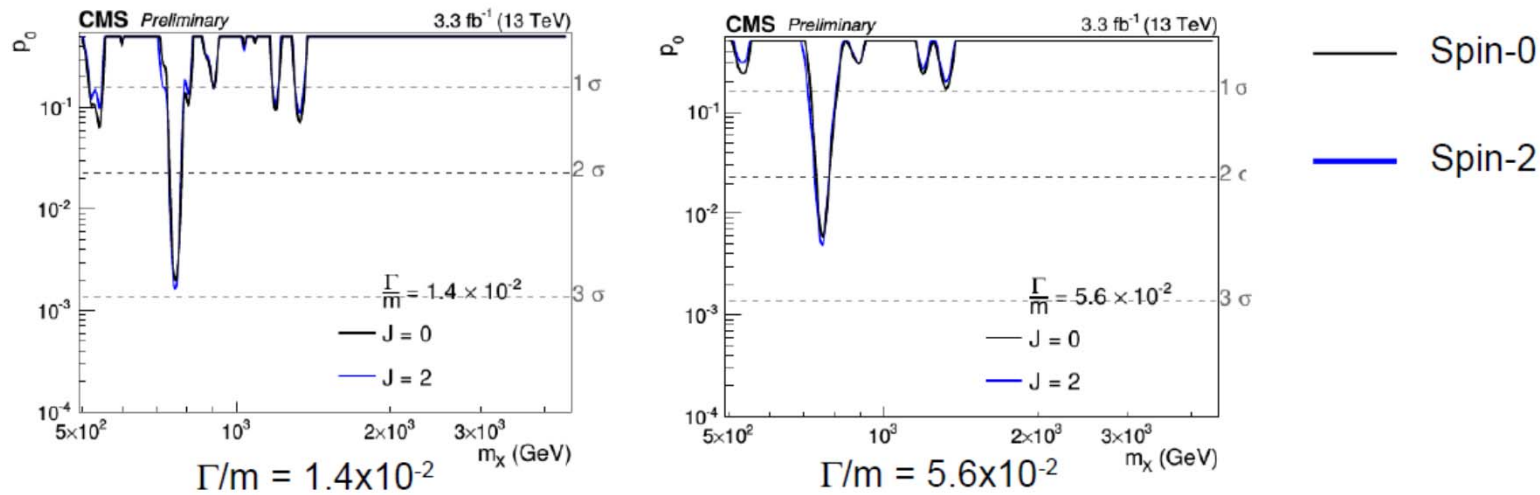




… All of these seem to have something…

# CMS (continued):

$\Gamma/m = 1.4\times10^{-4}$ $\Gamma/m = 1.4\times10^{-2}$ $\Gamma/m = 5.6\times10^{-2}$




$\Gamma/m = 1.4\times10^{-2}$ $\Gamma/m = 5.6\times10^{-2}$

Local significance ~ 2.8–2.9σ (globally not significant)

… Both narrow and wide widths are consistent

It seems fair to say that the excess is significant at a ~3σ level

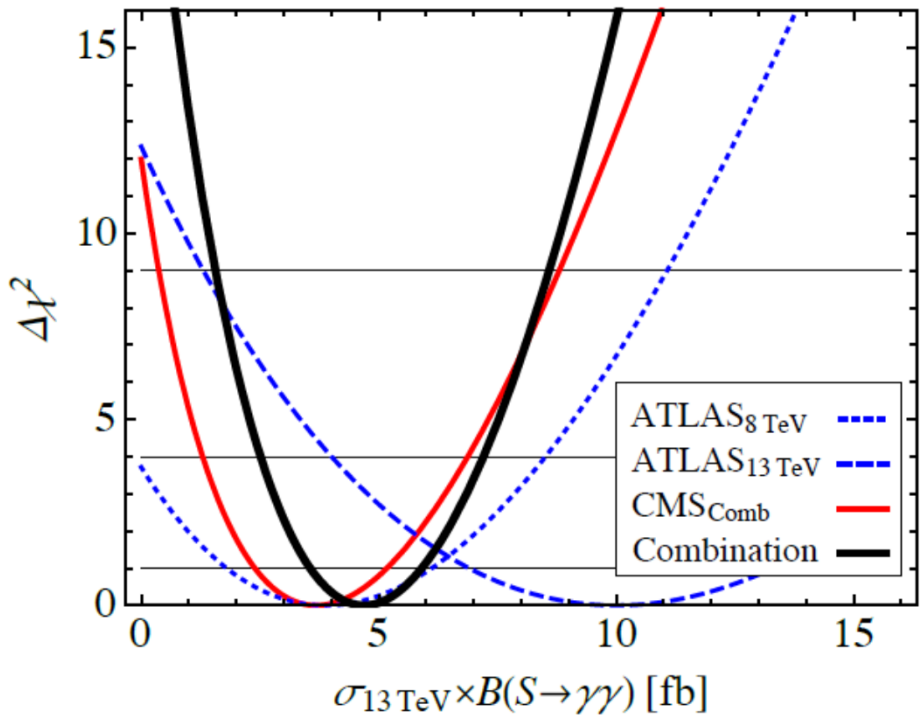
— If it remains, a major discovery of physics beyond the SM !

… worth studying the signal in detail

consistency with the 8 TeV data, compatibility with other searches, …

Indeed, lots of work

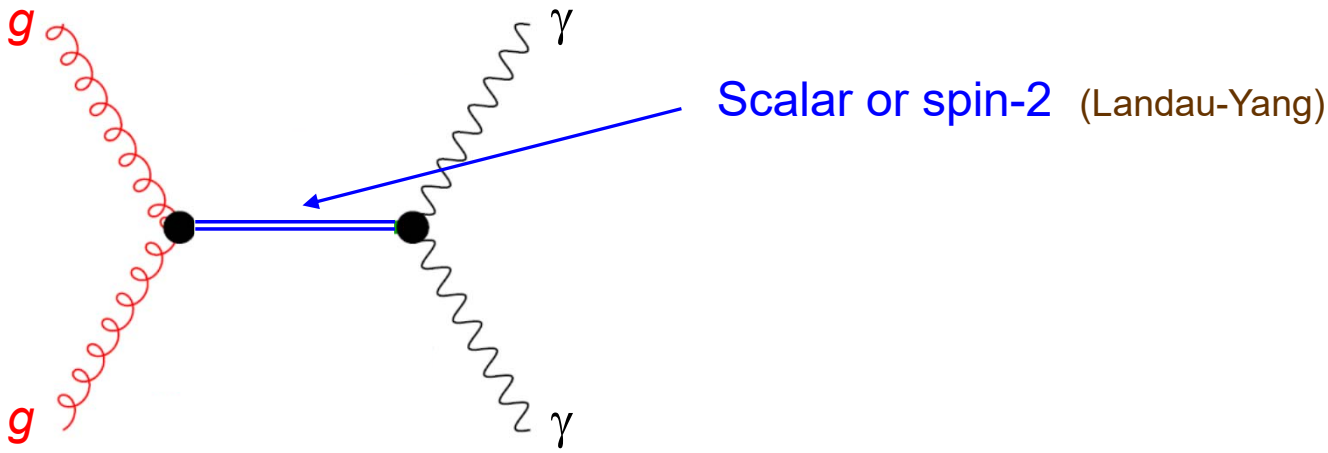
A relevant quantity:



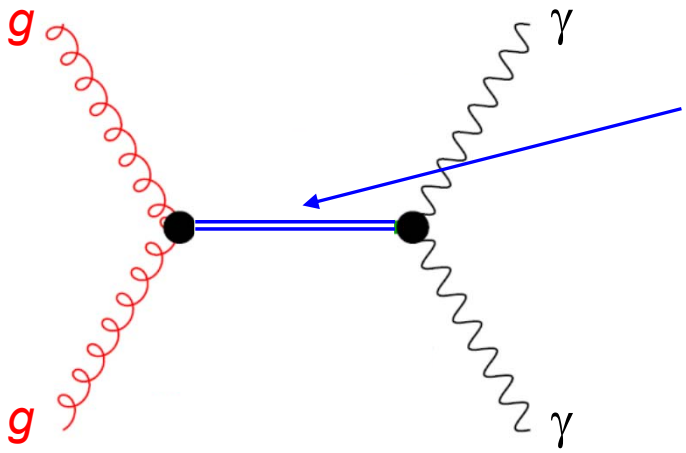

Buttazzo, Greljo, Isidori, Marzocca, arXiv:1604.3940

$\sigma_{pp \to S \to \gamma\gamma}$ ~ (3–7) fb … fairly large rate !

# What is going on?



# What is going on?



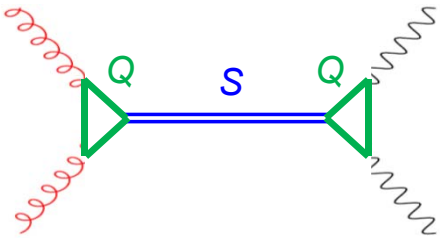

Scalar or spin-2 (Landau-Yang)

(I) A simplest perturbative scalar:

$\mathcal{L} \supset \lambda S Q \bar{Q}$

$$\sim \frac{1}{24\pi^2}\frac{\lambda S}{m_Q}\left(\frac{1}{2}g_3^2 G^a_{\mu\nu}G^{a\mu\nu} + 3(qe)^2 F_{\mu\nu}F^{\mu\nu}\right)$$

$$\longrightarrow \quad \sigma_{pp\to S\to\gamma\gamma} \sim 0.5\ \text{fb}\ \lambda^2 \left(\frac{q}{2/3}\right)^4 \left(\frac{600\ \text{GeV}}{m_Q}\right)^2$$




… requires a largeish coupling (though pseudoscalar, EM charge, multiplicity, …)

(II) Fundamental scalar

→ "hierarchy" problem

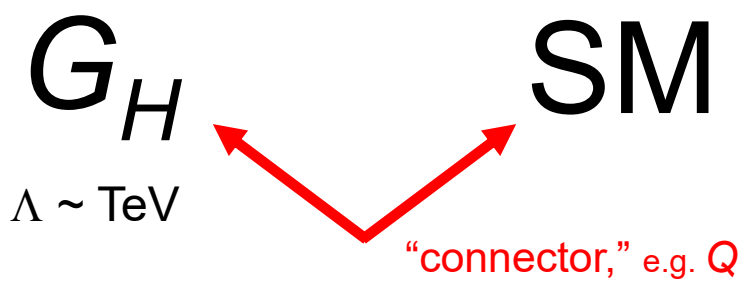
Unlike the SM Higgs, the problem does not seem to have an environmental solution.

These considerations lead us to consider (though not uniquely) ⟹

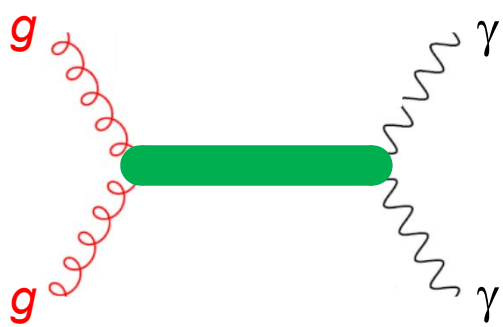
## A new strongly coupled sector at ~ TeV

… A composite scalar as the 750 GeV resonance

Harigaya, Y.N., PLB754,151 ('16) [arXiv:1512.04850]
… and many others




Technicolor — Weinberg; Susskind; Dimopoulos, Susskind; …
Composite Higgs — Georgi, Kaplan; Contino, Y.N., Pomarol; …
Kilic, Sundrum, Okui ('09); Kang, Luty ('08); Strassler, Zurek ('06); …




$Q\bar{Q}$, glueballs, $\eta'$, $\pi$, …

## Hidden pions (composite pseudo Nambu-Goldstone scalars)

Harigaya, Y.N.; Nakai, Sato, Tobioka; Franceschini *et al.*; Bian, Chen, Liu, Shu; Craig, Draper, Kilic, Thomas; Redi, Strumia, Tesi, Vigiani; ...

also Low, Tesi, Wang; Bellazzini, Franceschini, Sala, Serra; Matsuzaki, Yamawaki; No, Sanz, Setford; Bai, Berger, Lu; Belyaev, Cacciapaglia, Cai, Flacke, Parolini, Serõdio; ...

# How simple theoretically?

A “minimal” model consistent with all the observations (and with unification)

Harigaya, Y.N.

A Dirac fermion in the bifundamental representation of $G_H$ and SU(5) ↄ $G_{\mathrm{SM}}$

For given $G_H$, the theory has essentially only 3 (or 4 if CPV) free parameters

⟹ highly predictive!

(though strongly interacting → lattice)

# Model

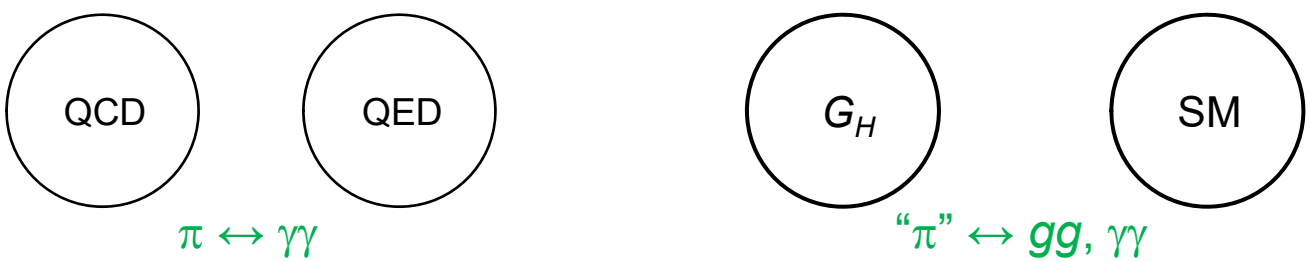
Harigaya, Y.N., PLB754,151 ('16) [arXiv:1512.04850]; JHEP 03, 091 ('16) [arXiv:1602.01092]

| | $G_H = SU(N)$ | $SU(3)_C$ | $SU(2)_L$ | $U(1)_Y$ |
|---|---|---|---|---|
| $\Psi_D$ | $\square$ | $\mathbf{3}^*$ | $\mathbf{1}$ | $1/3$ |
| $\Psi_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $-1/2$ |
| $\bar{\Psi}_D$ | $\bar{\square}$ | $\mathbf{3}$ | $\mathbf{1}$ | $-1/3$ |
| $\bar{\Psi}_L$ | $\bar{\square}$ | $\mathbf{1}$ | $\mathbf{2}$ | $1/2$ |

$$\mathcal{L} = -m_D \Psi_D \bar{\Psi}_D - m_L \Psi_L \bar{\Psi}_L + \text{h.c.}$$

… physics in terms of $\Lambda$, *mD*, *mL* (and $\theta_H$)

## Diphoton signal




$$\boxed{gg \rightarrow \text{“}\pi\text{”} \rightarrow \gamma\gamma}$$

# Hidden pions

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Dynamical condensation:

$$\langle \Psi_D \bar{\Psi}_D + \Psi_D^\dagger \bar{\Psi}_D^\dagger \rangle \approx \langle \Psi_L \bar{\Psi}_L + \Psi_L^\dagger \bar{\Psi}_L^\dagger \rangle \equiv -c$$

… $G_{SM}$ unbroken, $SU(5)_L \times SU(5)_R \to SU(5)_V$

$$\Longrightarrow \quad \boxed{\psi(\mathbf{8},\mathbf{1})_0, \qquad \chi(\mathbf{3},\mathbf{2})_{-5/6}, \qquad \varphi(\mathbf{1},\mathbf{3})_0, \qquad \phi(\mathbf{1},\mathbf{1})_0}$$

… hidden pions

Masses:

$$m_\psi^2 = 2m_D \frac{c}{f^2} + 3\Delta_C,$$

$$m_\chi^2 = (m_D + m_L)\frac{c}{f^2} + \frac{4}{3}\Delta_C + \frac{3}{4}\Delta_L + \frac{5}{12}\Delta_Y,$$

$$m_\varphi^2 = 2m_L \frac{c}{f^2} + 2\Delta_L,$$

$$m_\phi^2 = \frac{4m_D + 6m_L}{5}\frac{c}{f^2}.$$

coefficients … lattice

$$\Delta_C \simeq \frac{3g_3^2}{16\pi^2}\Lambda^2, \qquad \Delta_L \simeq \frac{3g_2^2}{16\pi^2}\Lambda^2, \qquad \Delta_Y \simeq \frac{3g_1^2}{16\pi^2}\Lambda^2$$

$$c \approx \frac{N}{16\pi^2}\Lambda^3, \qquad f \approx \frac{\sqrt{N}}{4\pi}\Lambda$$

… Colored particles ($\psi$ & $\chi$) are heavier

# Hidden pions

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… $G_{SM}$ unbroken, $SU(5)_L \times SU(5)_R \to SU(5)_V$

750 GeV resonance!

$$\Longrightarrow \quad \boxed{\psi(\mathbf{8},\mathbf{1})_0, \qquad \chi(\mathbf{3},\mathbf{2})_{-5/6}, \qquad \varphi(\mathbf{1},\mathbf{3})_0, \qquad \phi(\mathbf{1},\mathbf{1})_0}$$

… hidden pions

Interactions:

$$\begin{aligned}\mathcal{L} =& \frac{N g_3^2}{64\pi^2 f} d^{abc} \psi^a \epsilon^{\mu\nu\rho\sigma} G^b_{\mu\nu} G^c_{\rho\sigma} + \frac{N g_3 g_1}{32\sqrt{15}\pi^2 f} \psi^a \epsilon^{\mu\nu\rho\sigma} G^a_{\mu\nu} B_{\rho\sigma} \\ & - \frac{3N g_2 g_1}{64\sqrt{15}\pi^2 f} \varphi^\alpha \epsilon^{\mu\nu\rho\sigma} W^\alpha_{\mu\nu} B_{\rho\sigma} \\ & + \frac{N g_3^2}{32\sqrt{15}\pi^2 f} \phi\, \epsilon^{\mu\nu\rho\sigma} G^a_{\mu\nu} G^a_{\rho\sigma} - \frac{3N g_2^2}{64\sqrt{15}\pi^2 f} \phi\, \epsilon^{\mu\nu\rho\sigma} W^\alpha_{\mu\nu} W^\alpha_{\rho\sigma} - \frac{N g_1^2}{64\sqrt{15}\pi^2 f} \phi\, \epsilon^{\mu\nu\rho\sigma} B_{\mu\nu} B_{\rho\sigma}\end{aligned}$$

… determined by chiral anomalies

— $\psi$, $\varphi$, $\phi$ can be singly produced, while $\chi$ is only pair produced

— $\phi$ couples to both gluons and photons

## $\phi$:

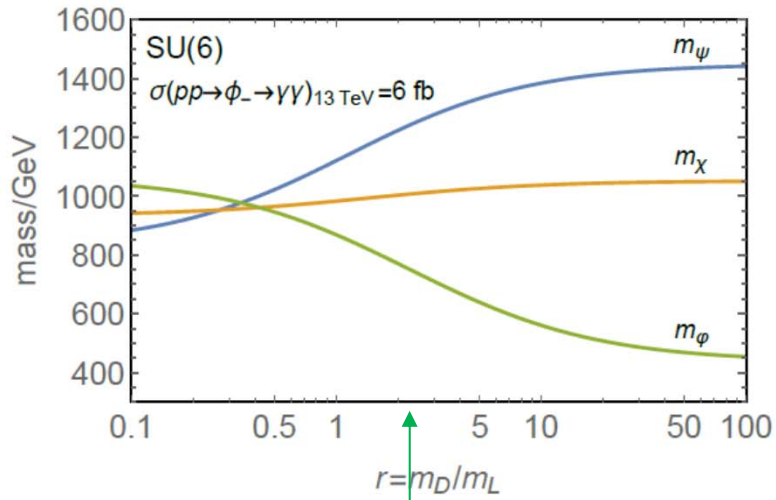
masses: $m_\phi \sim 750$ GeV

diphoton rate: $\sigma_{pp\to\phi\to\gamma\gamma} \sim (3\text{–}7)$ fb

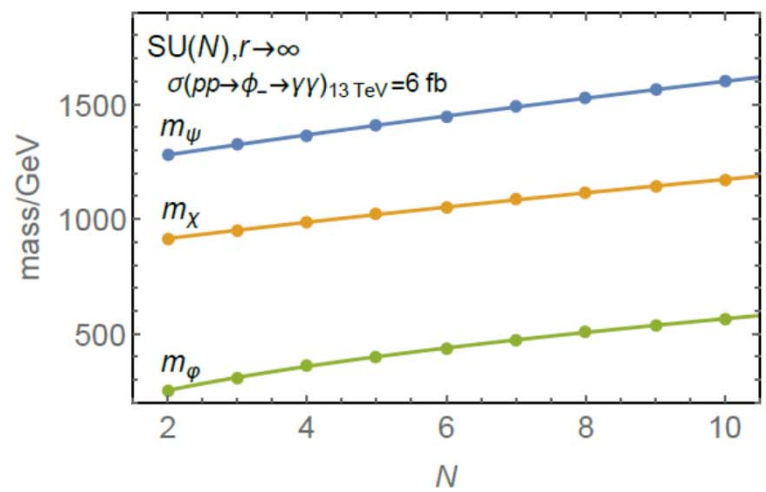
$$f \simeq 690 \text{ GeV} \frac{N}{6}\sqrt{\frac{6 \text{ fb}}{\sigma(pp\to\phi\to\gamma\gamma)}},$$

$$\frac{2m_D+3m_L}{5} \sim 80 \text{ GeV}\sqrt{\frac{6}{N}}\sqrt{\frac{\sigma(pp\to\phi\to\gamma\gamma)}{6 \text{ fb}}}$$

## Other hidden pions:




$m_D = m_L$ at $M_{GUT}$
$\to$ r ~ 1.5–3




$\Longrightarrow$ $m_\psi \lesssim 1.6$ TeV and $m_\chi \lesssim 1.2$ TeV

## Other diboson / dijet signals:

$$\frac{B_{\phi\to gg}}{B_{\phi\to\gamma\gamma}} = 8\left(\frac{6g_3^2}{14e^2}\right)^2 \simeq 200, \qquad \frac{B_{\phi\to WW}}{B_{\phi\to\gamma\gamma}} = 2\left(\frac{9}{14\sin^2\theta_W}\right)^2 \simeq 15,$$

$$\frac{B_{\phi\to ZZ}}{B_{\phi\to\gamma\gamma}} = \left(\frac{9+5\tan^4\theta_W}{14\tan^2\theta_W}\right)^2 \simeq 5, \qquad \frac{B_{\phi\to Z\gamma}}{B_{\phi\to\gamma\gamma}} = 2\left(\frac{9-5\tan^2\theta_W}{14\tan\theta_W}\right)^2 \simeq 2,$$

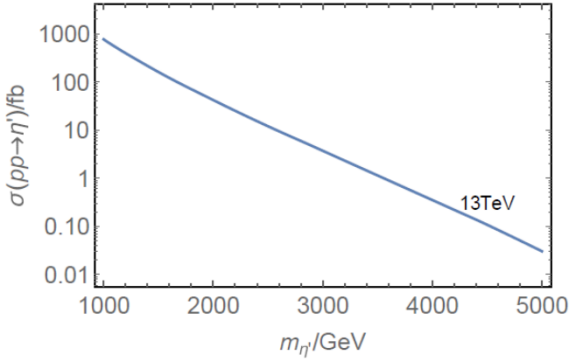
… consistent with all the 8 TeV & 13 TeV data!

# Higher resonances

- Hidden η'

$$m_{\eta'} \approx \sqrt{\frac{5}{N}}\,\Lambda \approx 3.2\ \mathrm{TeV}\sqrt{\frac{6\ \mathrm{fb}}{\sigma(pp \to \phi \to \gamma\gamma)}}$$

$$\mathcal{L} \approx \frac{N g_3^2}{32\sqrt{10}\pi^2 f}\eta'\,\epsilon^{\mu\nu\rho\sigma} G^a_{\mu\nu} G^a_{\rho\sigma} + \frac{N g_2^2}{32\sqrt{10}\pi^2 f}\eta'\,\epsilon^{\mu\nu\rho\sigma} W^\alpha_{\mu\nu} W^\alpha_{\rho\sigma} + \frac{N g_1^2}{32\sqrt{10}\pi^2 f}\eta'\,\epsilon^{\mu\nu\rho\sigma} B_{\mu\nu} B_{\rho\sigma}$$




~~CP~~: η' → ππ

CP: η' → πππ, *VV*

- Hidden ρ's and ω

Hidden ρ's mix with *V*'s

also $$\mathcal{L} \approx i\frac{\sqrt{N} g_3^2}{4\pi\Lambda^2} f^{abc}\left(D_\mu \rho^a_\nu - D_\nu \rho^a_\mu\right) G^{b\,\mu}_{\rho} G^{c\rho\nu}$$

Hidden ω does not mix with *V*

$$\mathcal{L} \approx \frac{\sqrt{N} g_3^3}{4\pi\Lambda^4}(\partial_\mu \omega_\nu) d^{abc} G^{a\nu\rho} G^b_{\rho\sigma} G^{c\sigma\mu}$$

- …

… Precise predictions require lattice calculations

# Would-be stable particles

$\chi$: Decays only through direct interactions

$$\mathcal{L} \sim \left\{ \begin{array}{c} \Psi_L \sigma_\mu \Psi_D^\dagger \\ \bar{\Psi}_D \sigma_\mu \bar{\Psi}_L^\dagger \end{array} \right\} \times \left\{ \begin{array}{c} q\sigma^\mu u^\dagger \\ e\sigma^\mu q^\dagger \\ d\sigma^\mu l^\dagger \end{array} \right\} + \text{h.c.}$$

$$\mathcal{L} \sim \left\{ \begin{array}{c} \bar{\Psi}_D \Psi_L \\ \Psi_D^\dagger \bar{\Psi}_L^\dagger \end{array} \right\} \times \left\{ \begin{array}{ll} qqh^\dagger, & ueh^\dagger \\ deh, & q^\dagger l^\dagger h^\dagger \\ u^\dagger u^\dagger h, & u^\dagger d^\dagger h^\dagger \end{array} \right\} + \text{h.c.}$$

$\longrightarrow \mathcal{L} = \alpha_1 (\partial_\mu \chi)(q\sigma^\mu u^\dagger) + \alpha_2 (\partial_\mu \chi)(e\sigma^\mu q^\dagger) + \alpha_3 (\partial_\mu \chi)(d\sigma^\mu l^\dagger) + \text{h.c.}$

$\longrightarrow \mathcal{L} = \beta_1 \chi qqh^\dagger + \beta_2 \chi ueh^\dagger + \beta_3 \chi deh + \beta_4 \chi q^\dagger l^\dagger h^\dagger + \beta_5 \chi u^\dagger u^\dagger h + \beta_6 \chi u^\dagger d^\dagger h^\dagger + \text{h.c.}$

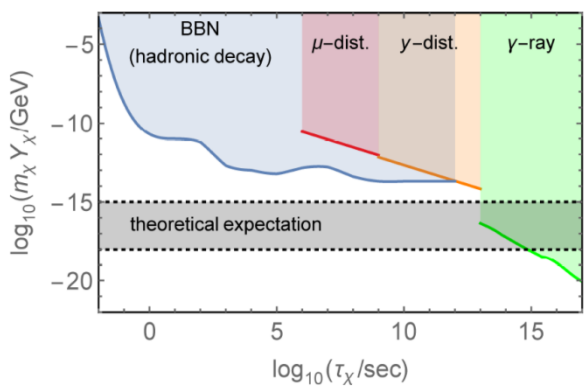
Coefficients could be enhanced by conformality in the UV

# LHC signals

Fast decay $\longrightarrow$ ~ leptoquark

Slow decay / Collider stable $\longrightarrow$ ~ *R* hadron

# Cosmology




$$10^{-8} \lesssim \Omega_\chi \lesssim 10^{-6}$$

$$\longrightarrow \quad \tau_\chi \lesssim 10^{13}\text{–}10^{15} \text{ sec}$$

# Similar considerations apply to hidden baryons as well

# Singlet extension

| | $G_H = SU(N)$ | $SU(3)_C$ | $SU(2)_L$ | $U(1)_Y$ |
|---|---|---|---|---|
| $\Psi_D$ | $\square$ | $\mathbf{3}^*$ | $\mathbf{1}$ | $1/3$ |
| $\Psi_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $-1/2$ |
| $\Psi_N$ | $\square$ | $\mathbf{1}$ | $\mathbf{1}$ | $0$ |
| $\bar{\Psi}_D$ | $\bar{\square}$ | $\mathbf{3}$ | $\mathbf{1}$ | $-1/3$ |
| $\bar{\Psi}_L$ | $\bar{\square}$ | $\mathbf{1}$ | $\mathbf{2}$ | $1/2$ |
| $\bar{\Psi}_N$ | $\bar{\square}$ | $\mathbf{1}$ | $\mathbf{1}$ | $0$ |

$SU(6)_L \times SU(6)_R \rightarrow SU(6)_D$

$$\psi(\mathbf{8},\mathbf{1})_0, \quad \chi(\mathbf{3},\mathbf{2})_{-5/6}, \quad \varphi(\mathbf{1},\mathbf{3})_0, \quad \phi(\mathbf{1},\mathbf{1})_0,$$
$$\xi(\mathbf{3},\mathbf{1})_{-1/3}, \quad \lambda(\mathbf{1},\mathbf{2})_{1/2}, \quad \eta(\mathbf{1},\mathbf{1})_0$$

… 35 – 24 = 11 extra hidden pions

# Singlet extension

| | $G_H = SU(N)$ | $SU(3)_C$ | $SU(2)_L$ | $U(1)_Y$ |
|---|---|---|---|---|
| $\Psi_D$ | $\square$ | $\mathbf{3}^*$ | $\mathbf{1}$ | $1/3$ |
| $\Psi_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $-1/2$ |
| $\Psi_N$ | $\square$ | $\mathbf{1}$ | $\mathbf{1}$ | $0$ |
| $\bar{\Psi}_D$ | $\bar{\square}$ | $\mathbf{3}$ | $\mathbf{1}$ | $-1/3$ |
| $\bar{\Psi}_L$ | $\bar{\square}$ | $\mathbf{1}$ | $\mathbf{2}$ | $1/2$ |
| $\bar{\Psi}_N$ | $\bar{\square}$ | $\mathbf{1}$ | $\mathbf{1}$ | $0$ |

$SU(6)_L \times SU(6)_R \to SU(6)_D$

$$\psi(\mathbf{8},\mathbf{1})_0, \quad \chi(\mathbf{3},\mathbf{2})_{-5/6}, \quad \boxed{\varphi(\mathbf{1},\mathbf{3})_0}, \quad \boxed{\phi(\mathbf{1},\mathbf{1})_0},$$
$$\xi(\mathbf{3},\mathbf{1})_{-1/3}, \quad \lambda(\mathbf{1},\mathbf{2})_{1/2}, \quad \eta(\mathbf{1},\mathbf{1})_0$$

… 35 – 24 = 11 extra hidden pions

$\phi$ and $\eta$ mix

$$\begin{pmatrix} m_\phi^2 & m_{\phi\eta}^2 \\ m_{\eta\phi}^2 & m_\eta^2 \end{pmatrix} = \begin{pmatrix} \frac{2}{5}(2m_D + 3m_L) & \frac{2}{5}(m_D - m_L) \\ \frac{2}{5}(m_D - m_L) & \frac{1}{15}(3m_D + 2m_L + 25m_N) \end{pmatrix} \frac{c}{f^2}$$

— Two diphoton resonances: $\phi$ and $\eta$

… apparent wide width, 750 GeV & 1.6 TeV, …

— Would-be stable particle can decay more easily

— Colored hidden pions $\psi$ & $\chi$ can be heavier

# Comments on UV

- Supersymmetry
  - — Superparticles at ~ 1–100 TeV
  - — Improved gauge coupling unification (~ MSSM)

    $\rightarrow$ $N \leq 4\text{-}5$
  - — Would-be stable particles easier to decay
  - — …

- Conformal dynamics
  - — Possible understanding of $\Lambda \sim m$
  - — …

- Superconformal dynamics
  - — Tightly constrained

    $\tilde{m}$ ~ TeV: $(N,F) = (3,7), (3,8)$; $\tilde{m}$ ~ 10 TeV: $(N,F) = (3,6), (4,10), (4,11)$ also allowed
  - — …

# Variations

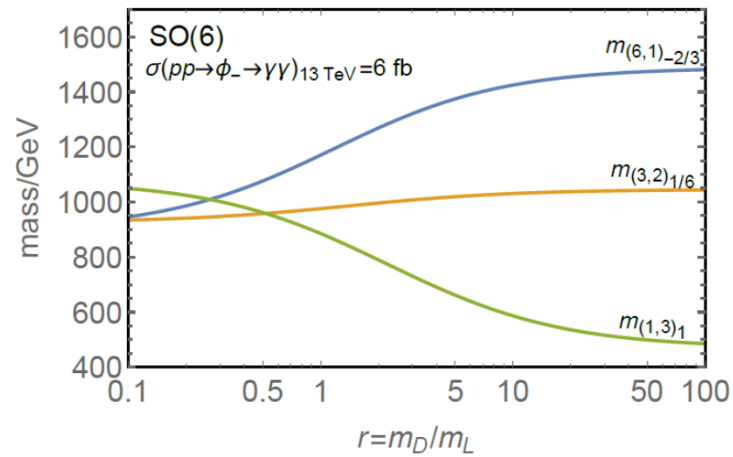
Harigaya, Y.N., arXiv:1603.05774

## $G_H$ = SO($N$)

| | $G_H = SO(N)$ | $SU(3)_C$ | $SU(2)_L$ | $U(1)_Y$ |
|---|---|---|---|---|
| $\Psi_D$ | $\square$ | $\mathbf{3}^*$ | $\mathbf{1}$ | $1/3$ |
| $\Psi_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $-1/2$ |
| $\bar{\Psi}_D$ | $\square$ | $\mathbf{3}$ | $\mathbf{1}$ | $-1/3$ |
| $\bar{\Psi}_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $1/2$ |

$SU(10)_{flavor} \rightarrow SO(10)$ [99 – 45 = 54]

Extra hidden pions: $(\mathbf{6},\mathbf{1})_{-2/3}$, $(\mathbf{3},\mathbf{2})_{1/6}$, $(\mathbf{1},\mathbf{3})_1$

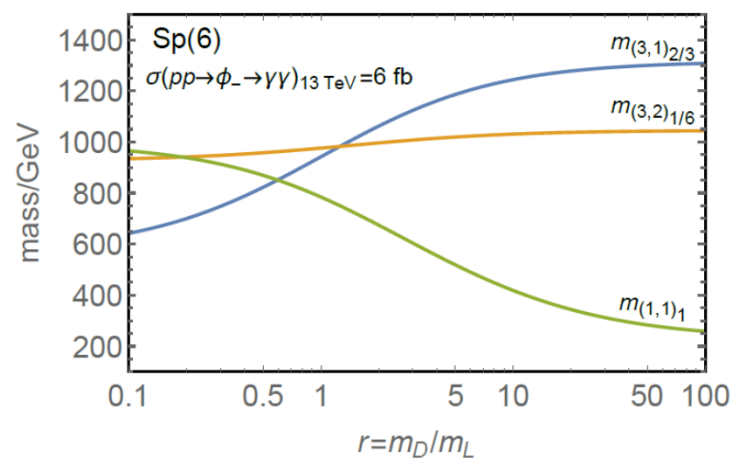



## $G_H$ = Sp($N$)

| | $G_H = Sp(N)$ | $SU(3)_C$ | $SU(2)_L$ | $U(1)_Y$ |
|---|---|---|---|---|
| $\Psi_D$ | $\square$ | $\mathbf{3}^*$ | $\mathbf{1}$ | $1/3$ |
| $\Psi_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $-1/2$ |
| $\bar{\Psi}_D$ | $\square$ | $\mathbf{3}$ | $\mathbf{1}$ | $-1/3$ |
| $\bar{\Psi}_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $1/2$ |

$SU(10)_{flavor} \rightarrow Sp(10)$ [99 – 55 = 44]

Extra hidden pions: $(\mathbf{3},\mathbf{1})_{2/3}$, $(\mathbf{3},\mathbf{2})_{1/6}$, $(\mathbf{1},\mathbf{1})_1$



# Singlet extensions

## $G_H$ = SO($N$)

| | $G_H = SO(N)$ | $SU(3)_C$ | $SU(2)_L$ | $U(1)_Y$ |
|---|---|---|---|---|
| $\Psi_D$ | $\square$ | $\mathbf{3}^*$ | $\mathbf{1}$ | $1/3$ |
| $\Psi_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $-1/2$ |
| $\bar{\Psi}_D$ | $\square$ | $\mathbf{3}$ | $\mathbf{1}$ | $-1/3$ |
| $\bar{\Psi}_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $1/2$ |
| $\Psi$ | $\square$ | $\mathbf{1}$ | $\mathbf{1}$ | $0$ |

$$\mathcal{L} = -m_D \Psi_D \bar{\Psi}_D - m_L \Psi_L \bar{\Psi}_L - \frac{m}{2}\Psi^2 + \text{h.c.}$$

$SU(11)_{flavor} \rightarrow SO(11)$ [120 – 55 = 65]

SU(N) with singlet + $(\mathbf{6},\mathbf{1})_{-2/3}$, $(\mathbf{3},\mathbf{2})_{1/6}$, $(\mathbf{1},\mathbf{3})_1$

## $G_H$ = Sp($N$)

| | $G_H = Sp(N)$ | $SU(3)_C$ | $SU(2)_L$ | $U(1)_Y$ |
|---|---|---|---|---|
| $\Psi_D$ | $\square$ | $\mathbf{3}^*$ | $\mathbf{1}$ | $1/3$ |
| $\Psi_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $-1/2$ |
| $\bar{\Psi}_D$ | $\square$ | $\mathbf{3}$ | $\mathbf{1}$ | $-1/3$ |
| $\bar{\Psi}_L$ | $\square$ | $\mathbf{1}$ | $\mathbf{2}$ | $1/2$ |
| $\Psi_1$ | $\square$ | $\mathbf{1}$ | $\mathbf{1}$ | $0$ |
| $\Psi_2$ | $\square$ | $\mathbf{1}$ | $\mathbf{1}$ | $0$ |

$$\mathcal{L} = -m_D \Psi_D \bar{\Psi}_D - m_L \Psi_L \bar{\Psi}_L - m \Psi_1 \Psi_2 + \text{h.c.}$$

$SU(12)_{flavor} \rightarrow Sp(12)$ [143 – 78 = 65]

SU(N) with singlet + $(\mathbf{3},\mathbf{1})_{2/3}$, $[(\mathbf{3},\mathbf{2})_{1/6}$, $(\mathbf{1},\mathbf{1})_1]$ x 2

This essentially exhausts all cases as far as hidden pion physics is concerned.

# Summary

The diphoton excess observed at the LHC
may be the first signal of BSM physics at the TeV scale

A natural possibility is that the resonance
is a composite scalar particle in a new strong sector at ~ TeV

— A hidden pion (pseudo Nambu-Goldstone boson)

Minimal models compatible with unification is consistent with the data
why we live in the universe we observe

… not obvious!

A class of highly predictive models

Full understanding of the theory (or this time, prediction!) requires lattice calculations

We will know in a few months !

Hopefully, the beginning of a new era

→ lots of interesting physics: UV (SUSY, conformal dynamics), unification, cosmology, …