

IMFP16

4-8 April 2016

Madrid

Theory of (non-SUSY) Beyond the Standard Model

JosØ Santiago (CAFPE and U. Granada)



What's new? (in non-SUSY BSM)

- We have data



SM

ATLAS Exotics Searches* - 95% CL Exclusion

Status: March 2016

ATLAS Preliminary

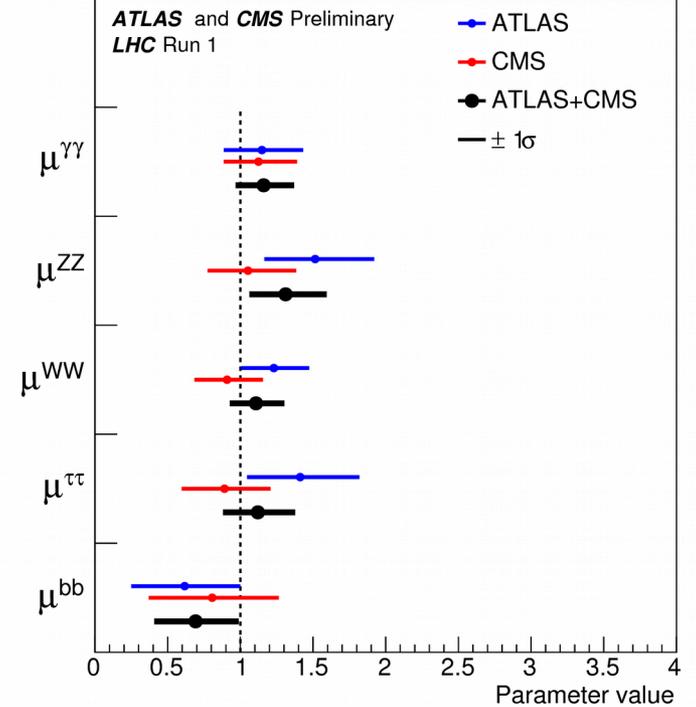
$$\int \mathcal{L} dt = (3.2 - 20.3) \text{ fb}^{-1}$$

$$\sqrt{s} = 8, 13 \text{ TeV}$$

Model	ℓ, γ	Jets†	E_T^{miss}	$[\mathcal{L} dt] [\text{fb}^{-1}]$	Limit	Reference
Extra dimensions						
ADD $G_{KK} + g/q$	-	≥ 1 J	Yes	3.2	M_{Pl} 6.88 TeV	Preliminary
ADD non-resonant $\ell\ell$	$2 e, \mu$	1 J	-	20.3	M_{Pl} 4.7 TeV	1407.2410
ADD OBH $\rightarrow \ell q$	$1 e, \mu$	1 J	-	20.3	M_{Pl} 5.2 TeV	1311.2006
ADD OBH	-	2 J	-	3.6	M_{Pl} 8.3 TeV	1512.01530
ADD BH high Σp_T	$\geq 1 e, \mu$	≥ 2 J	-	3.2	M_{Pl} 8.2 TeV	n = 6, $M_{\text{Pl}} = 3 \text{ TeV}$, rot BH
ADD BH multijet	-	≥ 3 J	-	3.6	M_{Pl} 9.55 TeV	n = 6, $M_{\text{Pl}} = 3 \text{ TeV}$, rot BH
RS1 $G_{KK} \rightarrow \ell\ell$	$2 e, \mu$	-	-	20.3	G_{KK} mass 2.68 TeV	$k/M_{\text{Pl}} = 0.1$
RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	-	20.3	G_{KK} mass 2.66 TeV	$k/M_{\text{Pl}} = 0.1$
Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\bar{v}$	$1 e, \mu$	1 J	Yes	3.2	G_{KK} mass 1.06 TeV	$k/M_{\text{Pl}} = 1.0$
Bulk RS $G_{KK} \rightarrow HH \rightarrow bbb\bar{b}$	-	4 b	-	3.2	G_{KK} mass 475-785 GeV	$k/M_{\text{Pl}} = 1.0$
Bulk RS $G_{KK} \rightarrow t\bar{t}$	$1 e, \mu$	$\geq 1 b, \geq 1 J/2$	Yes	20.3	G_{KK} mass 2.2 TeV	$BR = 0.925$
2UED / RPP	$1 e, \mu$	$\geq 2 b, \geq 4 J$	Yes	3.2	KK mass 1.46 TeV	Tier (1,1), $BR(A^{(1)} \rightarrow t\bar{t}) = 1$
Gauge bosons						
SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	3.2	Z' mass 3.4 TeV	ATLAS-CONF-2015-070
SSM $Z' \rightarrow \tau\tau$	2τ	-	-	19.5	Z' mass 2.02 TeV	1502.07177
Leptophobic $Z' \rightarrow b\bar{b}$	-	2 b	-	3.2	Z' mass 1.5 TeV	Preliminary
SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes	3.2	W' mass 4.07 TeV	ATLAS-CONF-2015-063
HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	$0 e, \mu$	1 J	Yes	3.2	W' mass 1.6 TeV	ATLAS-CONF-2015-068
HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model B	-	2 J	-	3.2	W' mass 1.38-1.6 TeV	ATLAS-CONF-2015-073
HVT $W' \rightarrow WH \rightarrow \ell\nu b\bar{b}$ model B	$1 e, \mu$	1-2 b, 1-0 J	Yes	3.2	W' mass 1.62 TeV	ATLAS-CONF-2015-074
HVT $Z' \rightarrow ZZ \rightarrow \nu\nu b\bar{b}$ model B	$0 e, \mu$	1-2 b, 1-0 J	Yes	3.2	Z' mass 1.76 TeV	ATLAS-CONF-2015-074
LRSM $W'_c \rightarrow t\bar{b}$	$1 e, \mu$	2 b, 0-1 J	Yes	20.3	W'_c mass 1.92 TeV	1410.4103
LRSM $W'_c \rightarrow t\bar{b}$	$0 e, \mu$	$\geq 1 b, 1 J$	-	20.3	W'_c mass 1.76 TeV	1408.0886
CI						
CI $qqqq$	-	2 J	-	3.6	Λ 17.5 TeV $\eta_{LL} = -1$	1512.01530
CI $qq\ell\ell$	$2 e, \mu$	-	-	3.2	Λ 23.1 TeV $\eta_{LL} = -1$	ATLAS-CONF-2015-070
CI $u\ell\ell\ell$	$2 e, \mu$ (SS)	$\geq 1 b, 1-4 J$	Yes	20.3	Λ 4.3 TeV $ \zeta_{LL} = 1$	1504.04605
DM						
Axial-vector mediator (Dirac DM)	$0 e, \mu, 1 \gamma$	$\geq 1 J$	Yes	3.2	m_X 1.0 TeV	Preliminary
Axial-vector mediator (Dirac DM)	$0 e, \mu, 1 \gamma$	1 J	Yes	3.2	m_X 650 GeV	$g_{\ell} = 0.25, g_{\tau} = 1.0, m(\chi) < 140 \text{ GeV}$
$ZZ_{\ell\ell}$ EFT (Dirac DM)	$0 e, \mu, 1 \gamma, \leq 1 J$	-	Yes	3.2	M_{ℓ} 550 GeV	$g_{\ell} = 0.25, g_{\tau} = 1.0, m(\chi) < 10 \text{ GeV}$
LO						
Scalar LQ 1 st gen	$2 e, \mu$	$\geq 2 J$	-	3.2	LQ mass 1.07 TeV	Preliminary
Scalar LQ 2 nd gen	2μ	$\geq 2 J$	-	3.2	LQ mass 1.03 TeV	$\beta = 1$
Scalar LQ 3 rd gen	$1 e, \mu$	$\geq 1 b, \geq 3 J$	Yes	20.3	LQ mass 640 GeV	$\beta = 0$
Heavy quarks						
VLQ $TT \rightarrow Ht + X$	$1 e, \mu$	$\geq 2 b, \geq 3 J$	Yes	20.3	T mass 855 GeV	T in (TB) doublet
VLQ $YY \rightarrow Wb + X$	$1 e, \mu$	$\geq 1 b, \geq 3 J$	Yes	20.3	Y mass 770 GeV	Y in (BY) doublet
VLQ $BB \rightarrow Hb + X$	$1 e, \mu$	$\geq 2 b, \geq 3 J$	Yes	20.3	B mass 735 GeV	isospin singlet
VLQ $BB \rightarrow Zb + X$	$2 \geq 3 e, \mu$	$\geq 2 \geq 1 b$	-	20.3	B mass 755 GeV	B in (BY) doublet
VLQ $QQ \rightarrow WqWq$	$1 e, \mu$	$\geq 4 J$	-	20.3	Q mass 690 GeV	
$T_{3/2} \rightarrow Wt$	$1 e, \mu$	$\geq 1 b, \geq 5 J$	Yes	20.3	$T_{3/2}$ mass 840 GeV	
Excited fermions						
Excited quark $q^* \rightarrow q\gamma$	1γ	1 J	-	3.2	q^* mass 4.4 TeV	only u^* and d^* , $\Lambda = m(q^*)$
Excited quark $q^* \rightarrow qg$	-	-	-	3.6	q^* mass 5.2 TeV	only u^* and d^* , $\Lambda = m(q^*)$
Excited quark $b^* \rightarrow b\gamma$	-	1 b, 1 J	-	3.2	b^* mass 2.1 TeV	
Excited quark $b^* \rightarrow Wt$	1 or 2 e, μ	1 b, 2-0 J	Yes	20.3	b^* mass 1.5 TeV	$f_{\ell} = f_{\tau} = 1$
Excited lepton ℓ^*	$3 e, \mu$	-	-	20.3	ℓ^* mass 3.0 TeV	$\Lambda = 3.0 \text{ TeV}$
Excited lepton ν^*	$3 e, \mu, \tau$	-	-	20.3	ν^* mass 1.6 TeV	$\Lambda = 1.6 \text{ TeV}$
Other						
LSTC $a_T \rightarrow W\gamma$	$1 e, \mu, 1 \gamma$	-	-	20.3	a_T mass 960 GeV	1407.8150
LFSM Majorana ν	$2 e, \mu$	2 J	-	20.3	N^{F} mass 2.0 TeV	$m(W_2) = 2.4 \text{ TeV}$, no mixing
Higgs triplet $H^{\pm\pm} \rightarrow \ell\ell$	$2 e, \mu$ (SS)	-	-	20.3	$H^{\pm\pm}$ mass 551 GeV	DY production, $BR(H^{\pm\pm} \rightarrow \ell\ell) = 1$
Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3 e, \mu, \tau$	-	-	20.3	$H^{\pm\pm}$ mass 400 GeV	DY production, $BR(H^{\pm\pm} \rightarrow \ell\tau) = 1$
Monopole (non-res prod)	$1 e, \mu$	1 b	Yes	20.3	spin-1 invisible particle mass 657 GeV	$a_{\text{non-res}} = 0.2$
Multi-charged particles	-	-	-	20.3	multi-charged particle mass 785 GeV	DY production, $ \zeta = 5e$
Magnetic monopoles	-	-	-	7.0	monopole mass 1.34 TeV	DY production, $ \zeta = 1_{\text{kg}}$, spin 1/2

*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

†Small-radius (large-radius) jets are denoted by the letter J (J).



What's new? (in non-SUSY BSM)



SM

- We have data
- The decade of 2000's was extremely rich in model-building ideas, driven mainly by naturalness (main reason to expect new physics at the LHC)
- Now that we have LHC data at 8 and 13 TeV it's time to confront these ideas with experimental data
- The stringent experimental constraints (direct searches, Higgs couplings) on many extensions on the SM creates some tension with natural models

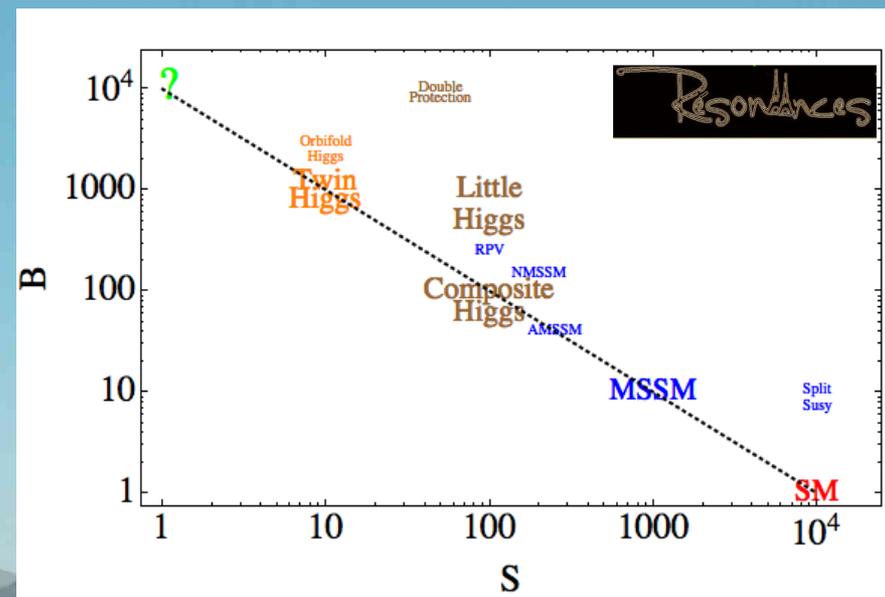
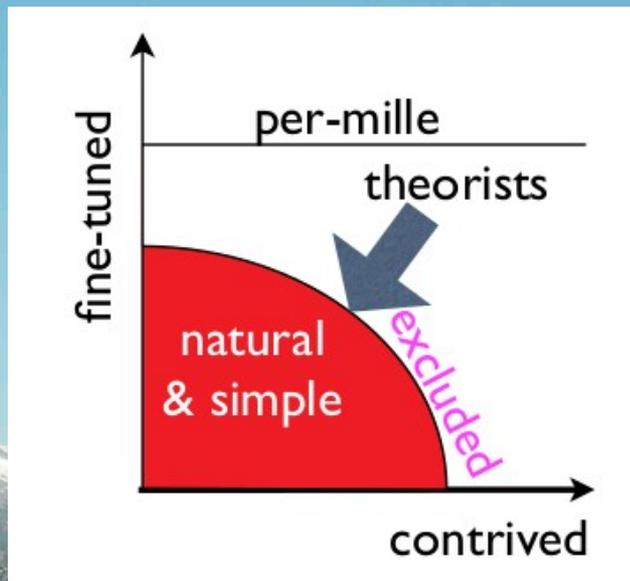
What's new? (in non-SUSY BSM)

- We have data
- More and more stringent bounds on the masses of new particles imply either more special (fine-tuned) or more baroque (~~complicated~~ rich) models



H. Murayama, Nobel
Symposium on LHC results

But beware that baroque-ness
is achieved by symmetries



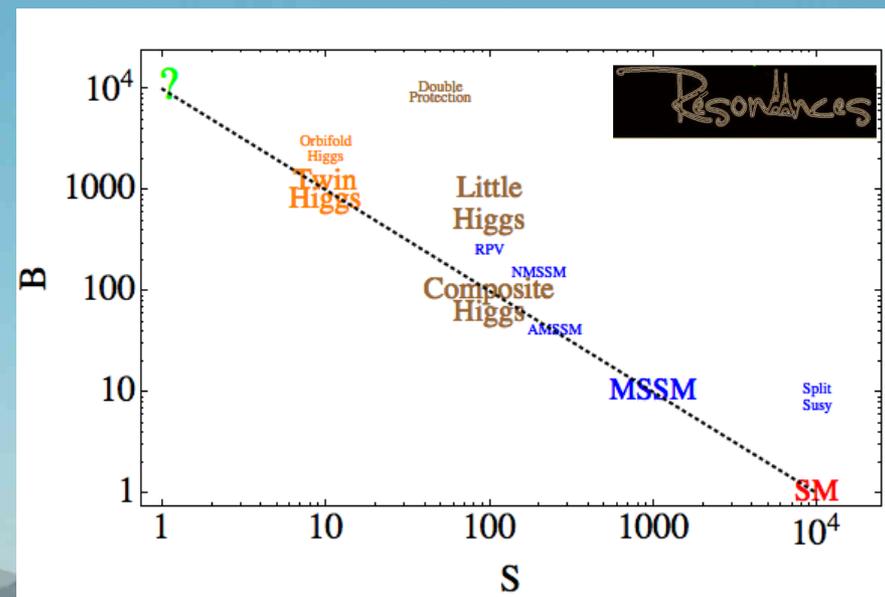
What's new? (in non-SUSY BSM)

- We have data
- More and more stringent bounds on the masses of new particles imply either more special (fine-tuned) or more baroque (~~complicated~~ rich) models



- B and S imply different experimental strategies:

- Larger S: keep looking (and hope you have kinematical reach)
- Larger B: try new strategies (expect cancellations, new channels, unexpected behaviour, ...)



What's new? (in non-SUSY BSM)

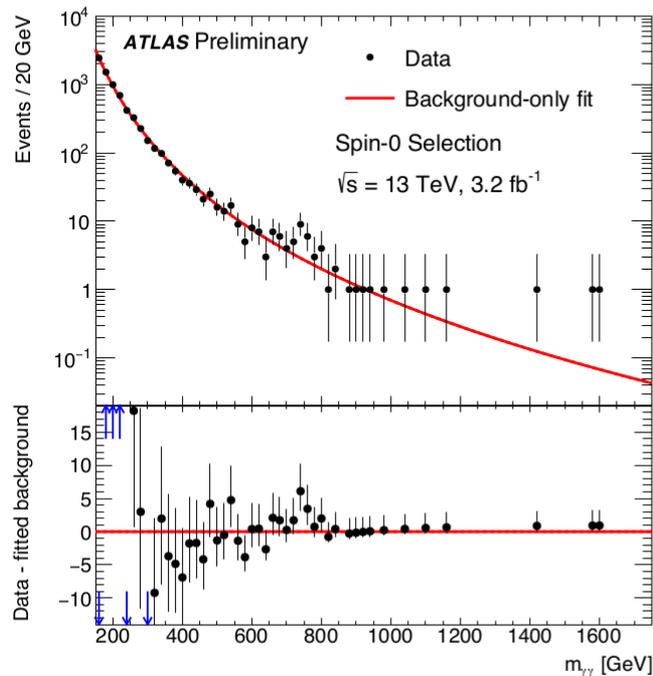
- ... and we have data



Results

SPIN-0 ANALYSIS

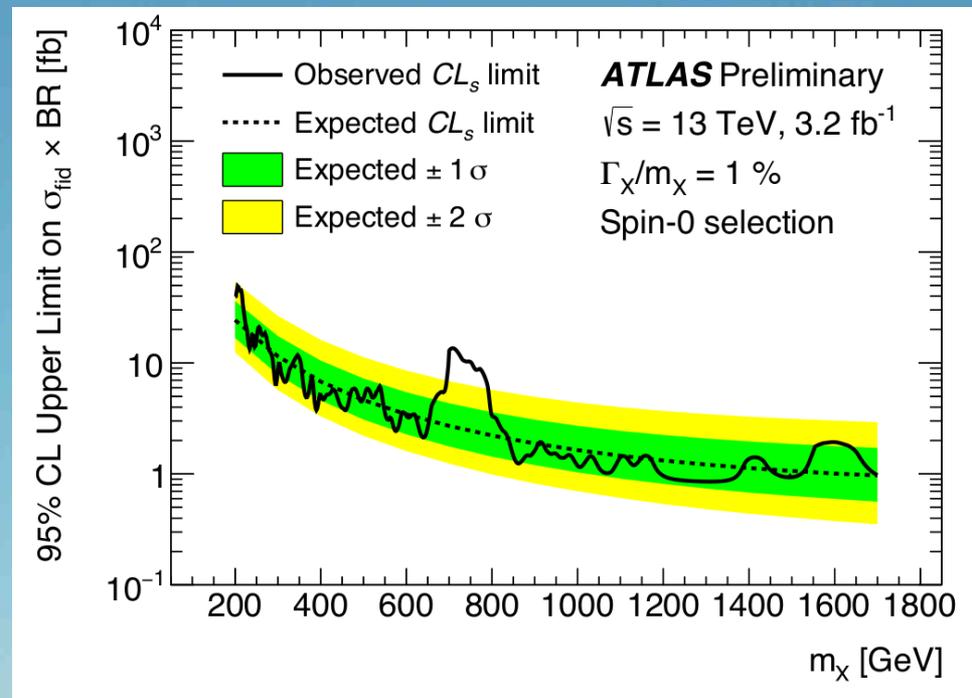
background-only fit



2878 events ($m_{\gamma\gamma} > 200$ GeV)

Marco Delmastro

Diphoton searches



What's new? (in non-SUSY BSM)



- ... and we have data
- Reported anomalies trigger the wild imagination of theorists
- It might be just a statistical fluctuation or the discovery of the century but it is an excellent model-building exercise (and a lot of fun!) finding possible explanations to the excesses

The Gold Rush: [INSPIRES][list]

Date	papers
16 Dec	10
25 Dec	101
1 Jan	137
1 Feb	212
1 Mar	263
1 Apr	?

Strumia, Moriond 2016

Outline

- Non-SUSY approaches to naturalness:
 - Composite pNGB Higgs:
 - Fine-tuning and baroqueeness
 - Phenomenological implications
 - Increasing elusiveness: neutral naturalness
 - No new TeV particles: cosmological relaxation
- Explaining anomalies: 750 diphoton
- Conclusions



Naturalness as guiding principle

- Naturalness problem: the mass of an elementary scalar is a relevant operator not (obviously) protected by any symmetry (it is quadratically sensitive to any UV new physics)
- It is difficult to understand the scale of EWSB unless some new structure appears around the TeV scale (within LHC reach) [counter example later]
- Currently tested tuning is not yet dramatic

$$\frac{\delta m_H^2}{m_H^2} \sim \frac{\Lambda^2}{4\pi^2 m_H^2} \leq \Delta \Rightarrow \Lambda \lesssim \text{few } \sqrt{\Delta} m_H \sim \text{few} \begin{cases} 1 \text{ TeV, } 0.01 \text{ tuning} \\ 3 \text{ TeV, } 0.001 \text{ tuning} \end{cases}$$

Crude estimate

Naturalness as guiding principle

- Naturalness is still a good guiding principle:
 - Tuning still at the \sim per-cent level
 - It is the main argument for new physics at the LHC (dark matter, baryon asymmetry, flavor, ..., could be related to TeV physics or not)
 - Increasing the degree of baroqueness changes the collider phenomenology (cancelations imposed by symmetries, elusive new physics)



The Higgs as a composite pNGB

- Is the Higgs boson the first elementary scalar observed in Nature?
- Known examples of SSB and/or light scalars involve composite scalars:
 - Superconductivity: electron (Cooper) pairs condense due to their interactions with the phonons in a crystal
 - Pions are composite pNGB of chiral symmetry breaking
- Maybe the Higgs is also a composite state of a new strongly interacting theory?



The Higgs as a composite pNGB

- A naturally light composite Higgs: Ingredients
 - H as a pNGB: Georgi, Kaplan '80, ...
 - A new strongly coupled sector condenses at a scale $f \sim \text{TeV}$ spontaneously breaking a global symmetry: H is the NGB of the breaking
 - Why NGB? To generate its potential from a weakly coupled sector (that breaks explicitly the global symmetry)

$$\delta m_H^2 \sim \frac{g^2}{16\pi^4} M^2$$

Weak coupling

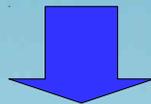
The Higgs as a composite pNGB

- A naturally light composite Higgs: Ingredients
 - H as a pNGB: Georgi, Kaplan '80, ...
 - A new strongly coupled sector condenses at a scale $f \sim \text{TeV}$ spontaneously breaking a global symmetry: H is the NGB of the breaking
 - Why NGB? To generate its potential from a weakly coupled sector (that breaks explicitly the global symmetry)
 - $v = f \sin(\langle h \rangle / f)$
 - $\xi \equiv \frac{v^2}{f^2}$ parameterizes deviations of Higgs couplings (and minimal fine-tuning)

The Higgs as a composite pNGB

- Realistic example: Minimal Composite Higgs Model
 - $SO(5)/SO(4) \times P_{LR}$ Agashe, Contino, (Da Rold), Pomarol '05 ('06)
 - Custodial protection of T and $Z b_L \bar{b}_L$ [$SO(4) \sim SU(2)_L \times SU(2)_R$]
 - 4 NGB transforming as a 4 of $SO(4)$ [just like the SM Higgs]
 - Explicit symmetry breaking by weak gauging (SM) and Yukawa couplings (mainly top)

$$V[H] = -\alpha f^2 \sin^2(H/f) + \beta f^2 \sin^4(H/f)$$



$$\xi = \alpha/(2\beta) \quad m_H^2 = 8\xi(1 - \xi)\beta$$

The Higgs as a composite pNGB

- Realistic example: Minimal Composite Higgs Model
 - $SO(5)/SO(4) \times P_{LR}$ Agashe, Contino, (Da Rold), Pomarol '05 ('06)

$$V[H] = -\alpha f^2 \sin^2(H/f) + \beta f^2 \sin^4(H/f) \quad \xi = \alpha/(2\beta)$$
$$m_H^2 = 8\xi(1 - \xi)\beta$$

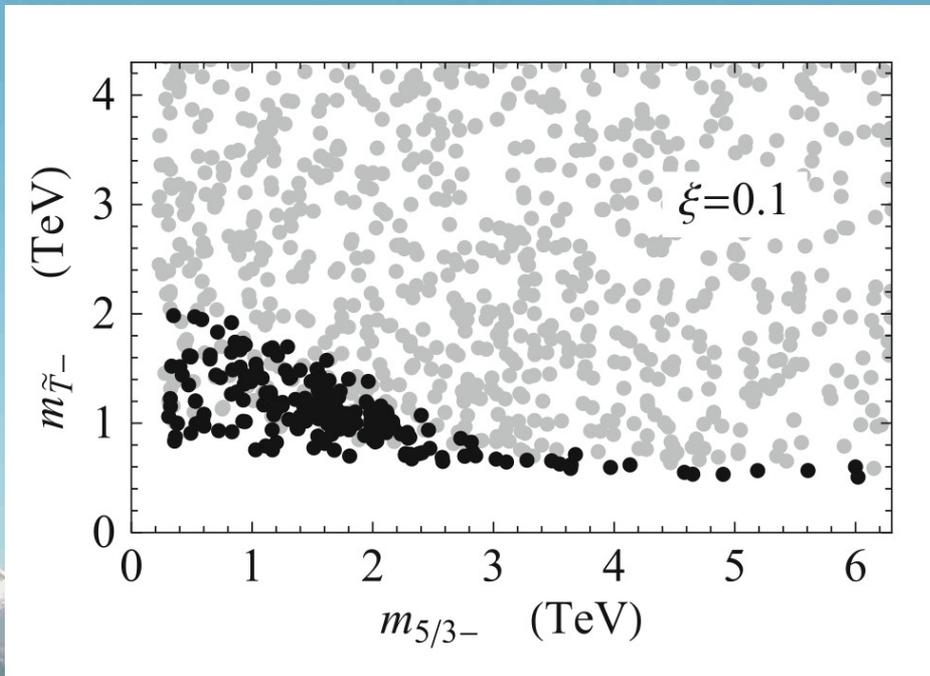
- α and β depend on the fermion quantum numbers:

$$- \alpha_{5\oplus 5} \sim \frac{N_c}{16\pi^2} \lambda_t^2 m_\rho^2 \quad \beta_{5\oplus 5} \sim \frac{N_c}{16\pi^2} \lambda_t^4 f^2 \quad \Delta_{5\oplus 5} \sim \frac{m_\rho^2}{\lambda_t^2 f^2} \frac{1}{2\xi}$$

$$- \alpha_{14\oplus 1} \sim \beta_{14\oplus 1} \sim \frac{N_c}{16\pi^2} \lambda_t^2 m_\rho^2 \quad \Delta_{14\oplus 1} \sim \frac{1}{2\xi}$$

The Higgs as a composite pNGB

- Realistic example: Minimal Composite Higgs Model
 - $SO(5)/SO(4) \times P_{LR}$ Agashe, Contino, (Da Rold), Pomarol '05 ('06)
 - The Higgs mass also imposes constraints (on the masses of fermionic resonances) $\frac{m_H}{m_t} \sim \sqrt{\frac{N_c}{2\pi^2} \frac{M_\psi}{f}}$



But also alternatives with no light top partners: lepton partners contribution to Higgs potential [Carmona, Goertz '13]

The Higgs as a composite pNGB

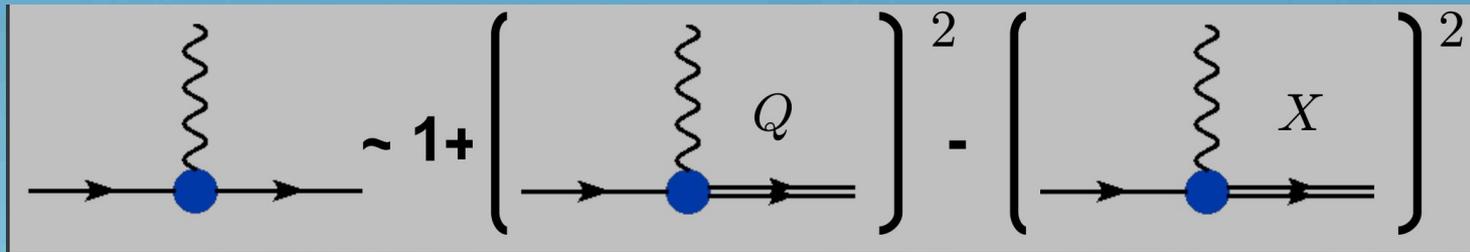
- How baroque is it? Not bad. Fermion resonances:

$$5_{\frac{2}{3}} \sim (2, 2)_{\frac{2}{3}} \oplus (1, 1)_{\frac{2}{3}} \sim 2_{\frac{1}{6}} \oplus 2_{\frac{7}{6}} \oplus 1_{\frac{2}{3}}$$
$$\begin{pmatrix} T \\ B \end{pmatrix} \quad \begin{pmatrix} X_{\frac{5}{3}} \\ T' \end{pmatrix} \quad \tilde{T}$$

- Not “just new vector-like quarks” (they come with a rich structure)
 - Cancellations are natural (large mixings allowed)
 - Large contributions to certain observables not only allowed but sometimes needed
 - Many new particles with large couplings (unusual behaviour)

The Higgs as a composite pNGB

- Not “just new vector-like quarks”
 - Cancellations are natural (large mixings allowed)
 - $\begin{pmatrix} T \\ B \end{pmatrix} \begin{pmatrix} X_{3/2} \\ T' \end{pmatrix}$ mix with u_R in a custodially symmetric way



$$1 + \left(\frac{\lambda_Q v}{M_Q} \right)^2 - \left(\frac{\lambda_X v}{M_X} \right)^2$$

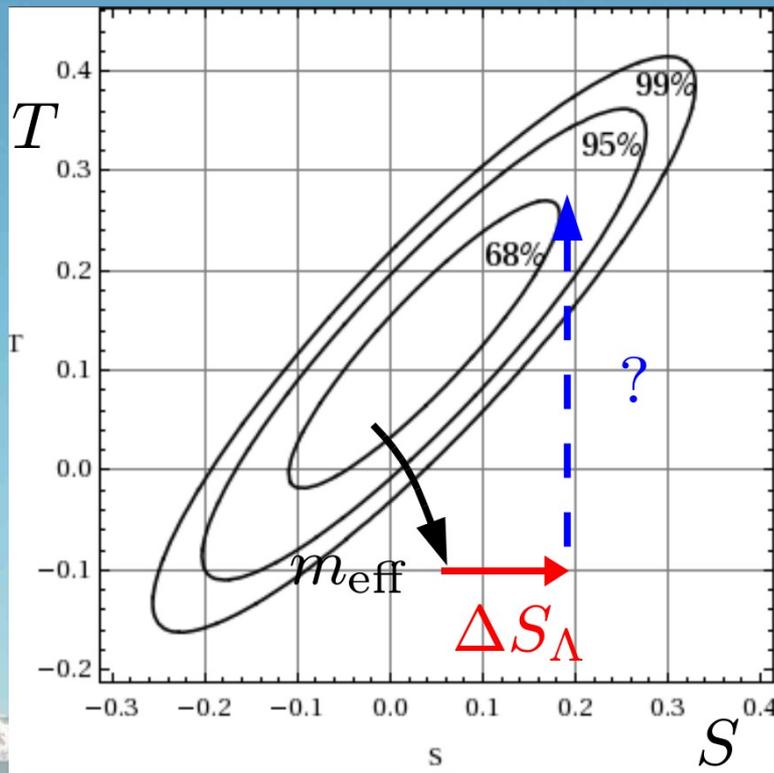
- Large mixing with valence quarks implies huge single production cross sections: excellent reach

Atre et al (JS) '09, '11

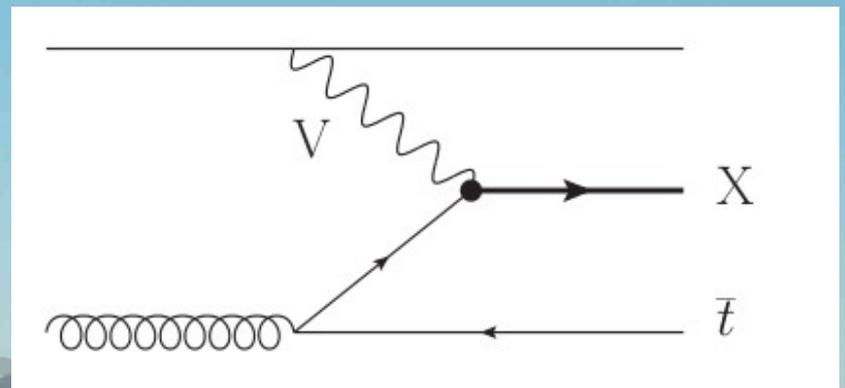
ATLAS-CONF-2012-137

The Higgs as a composite pNGB

- Not “just new vector-like quarks”
 - Large contributions to certain observables not only allowed but sometimes needed

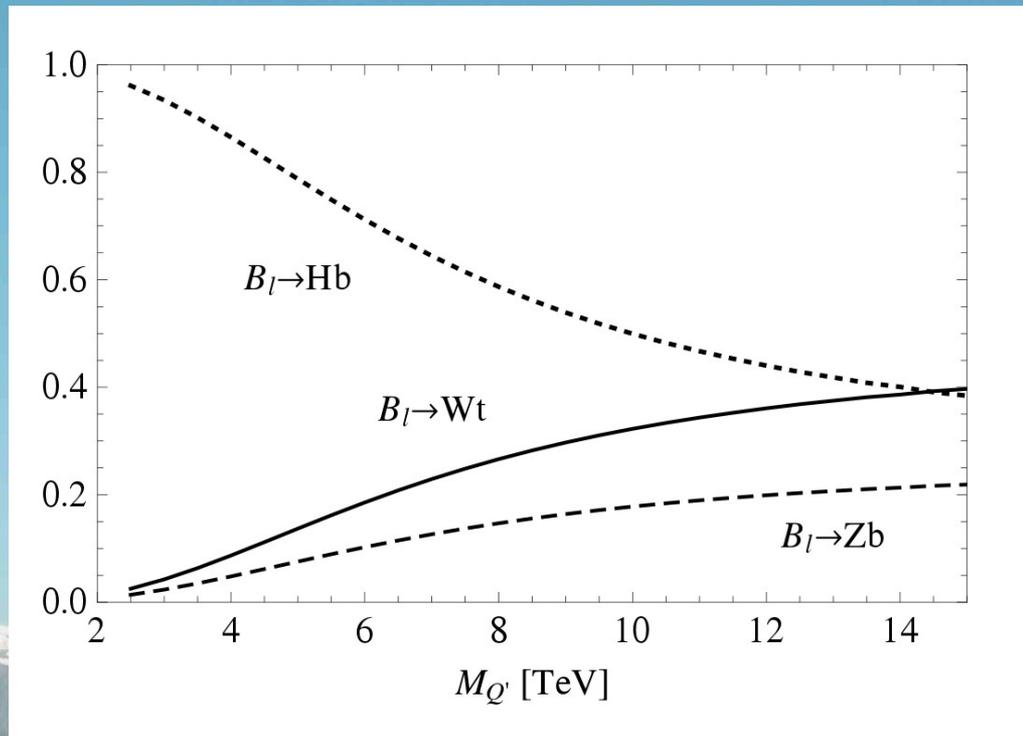


- Contributions to T and Zbb strongly correlated
 - Carena, Pont n, JS, Wagner '06, '07
 - Anastasiou, Furlan, JS '09
- Large mixing: single production relevant



The Higgs as a composite pNGB

- Not “just new vector-like quarks”
 - Many new particles with large couplings (unusual behaviour)
 - Large mixing with heavier particles (beyond the LHC reach) can dramatically change the behaviour

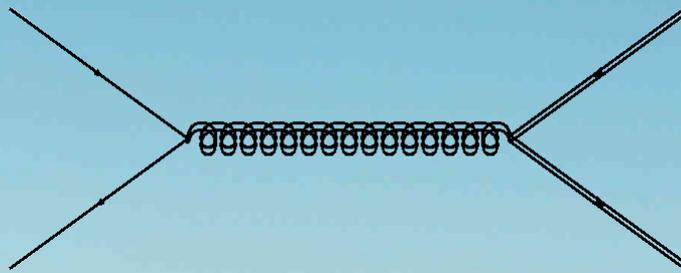


Chala, JS '13

$$M_{B_l} = 1 \text{ TeV}$$

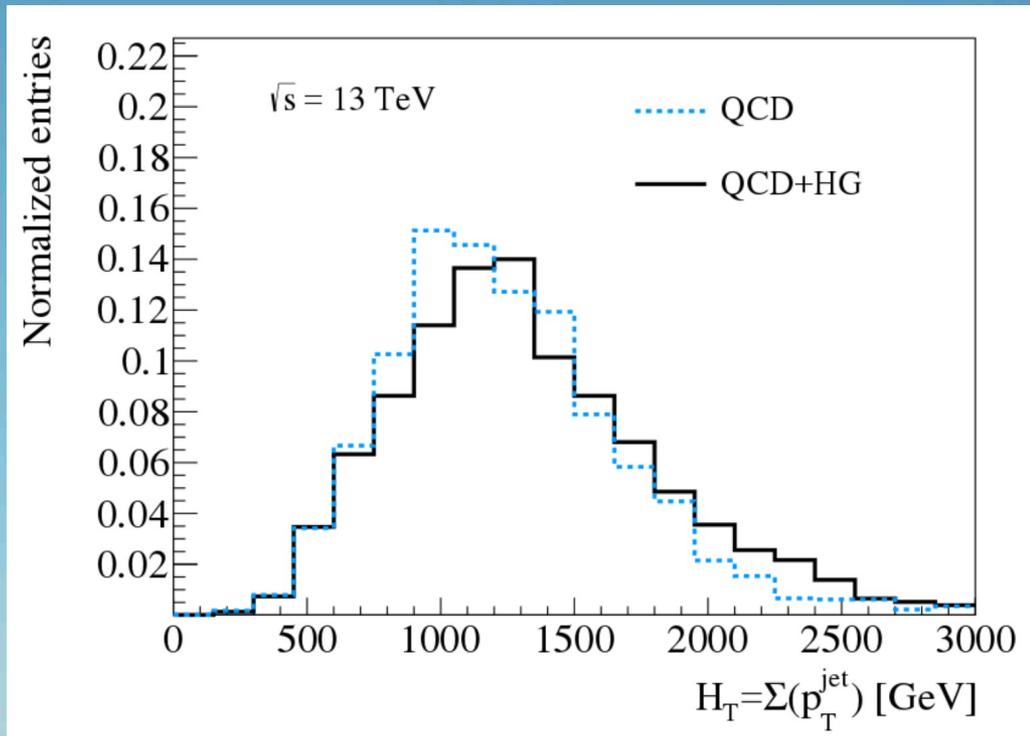
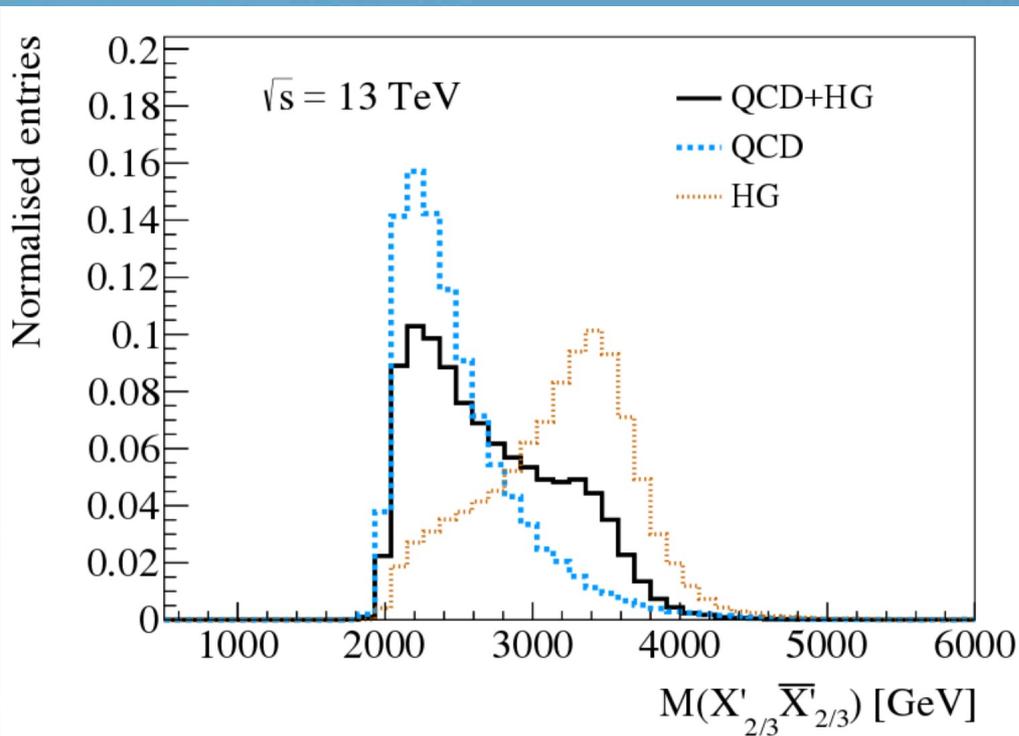
The Higgs as a composite pNGB

- Not “just new vector-like quarks”
 - Many new particles with large couplings (unusual behaviour)
 - Pair-production of VLQ can be mediated by new particles (heavy gluon): no longer model-independent.
 - Current searches assume QCD production. Are we sensitive to the different kinematics? Not yet (maybe with boosted techniques)



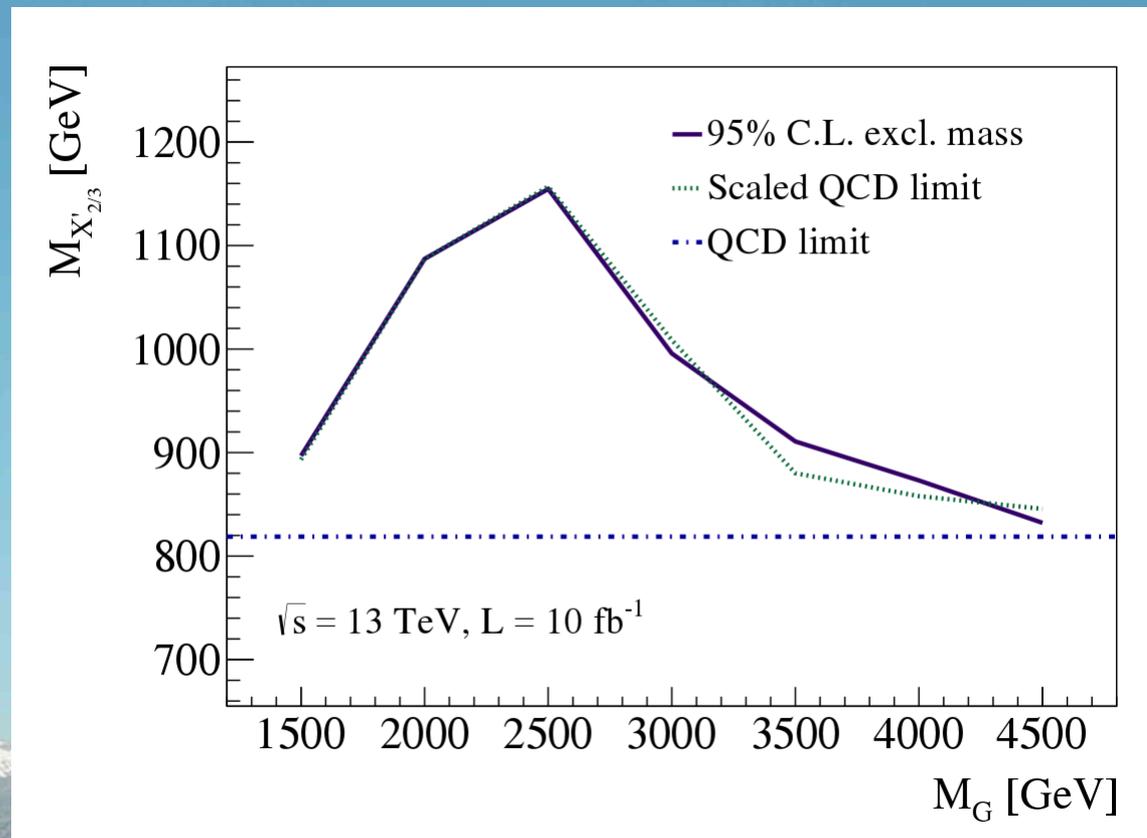
The Higgs as a composite pNGB

- Not “just new vector-like quarks” Araque, Castro, JS '15
- Current searches assume QCD production. Are we sensitive to the different kinematics? Not yet (maybe with boosted techniques)



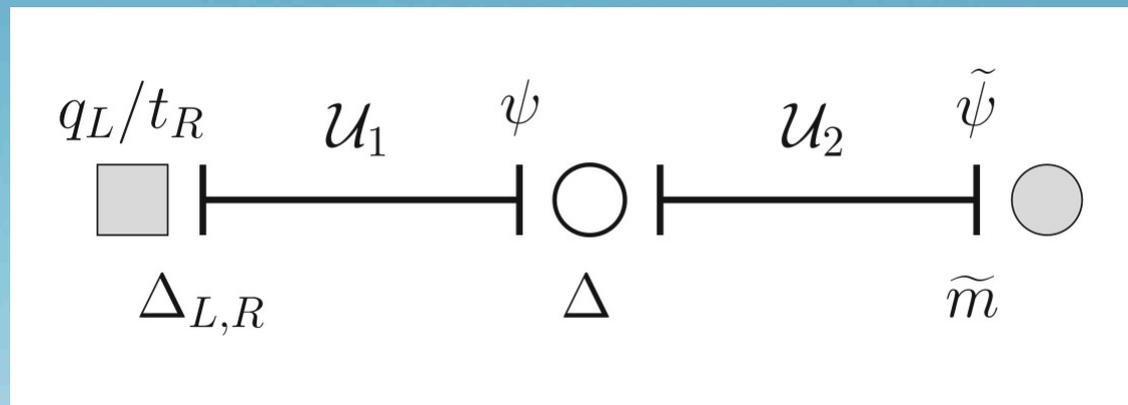
The Higgs as a composite pNGB

- Not “just new vector-like quarks” Araque, Castro, JS '15
- Current searches assume QCD production. Are we sensitive to the different kinematics? Not yet (maybe with boosted techniques)



Beyond the MCHM

- Can we do better?
 - One loop quadratic divergencies can be totally cancelled if the global symmetry is explicitly broken only when two different couplings are different from zero (collective symmetry breaking a la Little Higgs)



- Potential fully calculable in terms of low energy spectrum

Beyond the MCHM

- Uncolored top partners? Neutral naturalness

Chacko, Goh, Harnik '06

- So far the particles regulating the quadratic divergencies are charged under the SM (top partners are colored) and are therefore easy to produce at the LHC
- If the SM is doubled, the Higgs is the pNGB of a global symmetry that contains both copies and there is a Z_2 symmetry exchanging the two copies, the partners are charged under the (dark) copy SM but not under the SM
- SM-neutral partners difficult to produce at the LHC:

- Effects on Higgs couplings

Craig, Katz, Strassler, Sundrum '15

- Possible displaced vertices and hidden-valley pheno

Naturalness without TeV particles?

Graham, Kaplan, Rajendran '15

- Can we go even further and have a natural theory with no new particles at the TeV? Cosmological relaxation
 - Higgs mass at its natural (cut-off) value
 - Field-dependent contribution to the Higgs mass scans different values during inflation
 - When the Higgs mass becomes negative, it triggers a potential for the new field that freezes and stops the scanning
 - Replace the Higgs mass with a (small) parameter that is technically natural (stable under radiative corrections).



Natural without TeV particles?

Graham, Kaplan, Rajendran '15

- Can we go even further and have a natural theory with no new particles at the TeV? Cosmological relaxation.

$$V(h, \phi) = -\frac{\Lambda h^2}{2} \left(1 - g \frac{\phi}{\Lambda}\right) + g\Lambda^3 \phi + \epsilon \Lambda_c^3 h \cos(\phi/f)$$

- $\phi > \Lambda/g \Rightarrow \langle h \rangle = 0$
- ϕ slow rolls during inflation ($g \ll 1$), scanning h mass
- When $\phi \leq \Lambda/g \Rightarrow \langle h \rangle \neq 0$ and the last term induces a potential for ϕ , which stops rolling (and therefore the scan)

Natural without TeV particles?

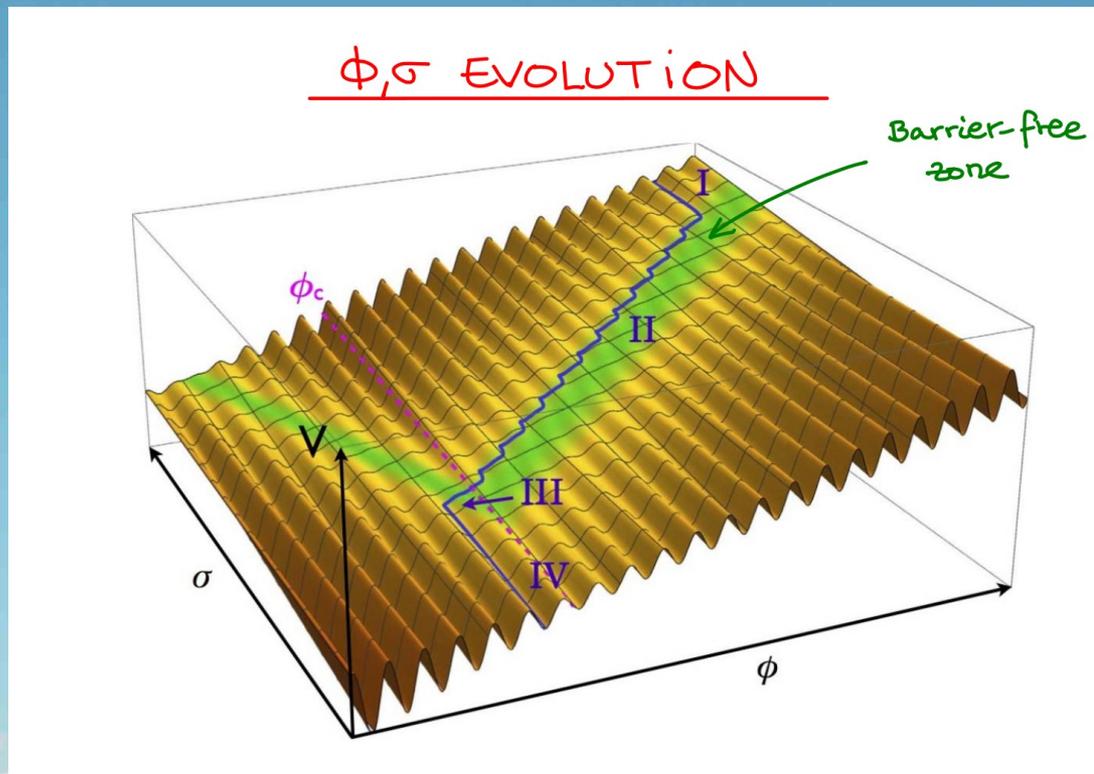
- Can we go even further and have a natural theory with no new particles at the TeV? Cosmological relaxation.

$$V(h, \phi) = -\frac{\Lambda h^2}{2} \left(1 - g \frac{\phi}{\Lambda} \right) + g \Lambda^3 \phi + \epsilon \Lambda_c^3 h \cos(\phi/f)$$

- Simplest option: ϕ QCD axion (problems with θ_{QCD})
- Alternative: change last term to $\epsilon \Lambda_c^2 h^2 \cos(\phi/f)$
 - Λ_c not related to QCD but this term is not radiatively stable
 - Can be made natural by introducing a second relaxation field

Natural without TeV particles?

- Can we go even further and have a natural theory with no new particles at the TeV? Cosmological relaxation.



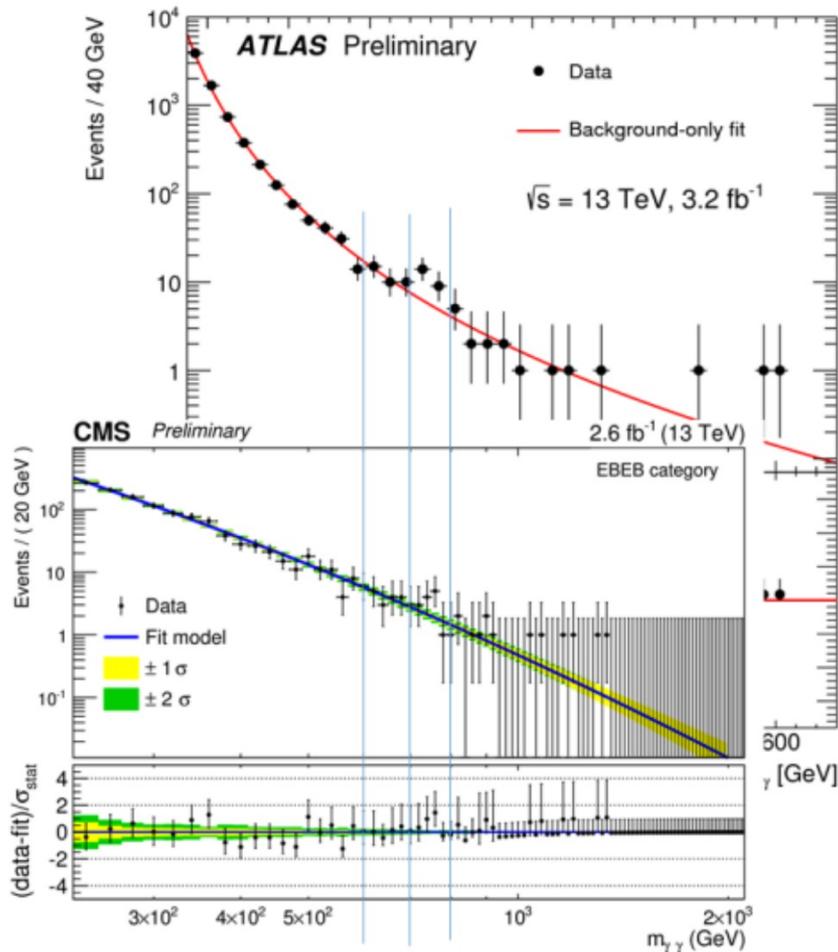
$$\Lambda \lesssim 10^6 \text{ TeV}$$

- Only particles below Λ : ϕ, σ
 $m_\phi \in [10^{-20}, 10^2] \text{ GeV}$
 $m_\sigma \in [10^{-45}, 10^{-2}] \text{ GeV}$
- Very suppressed couplings to SM: no collider signatures
- Possible axion-like DM candidates

- Let's change gears



First LHC data at 13 TeV



$\gamma\gamma$ peak around 750 GeV over flatland

$\sigma(pp \rightarrow \gamma\gamma)$	CMS	ATLAS
8 TeV	$(0.5 \pm 0.6) \text{ fb}$	$(0.4 \pm 0.8) \text{ fb}$
13 TeV	$(6 \pm 3) \text{ fb}$	$(10 \pm 3) \text{ fb}$

Theoretically clean.

Experimentally simple.

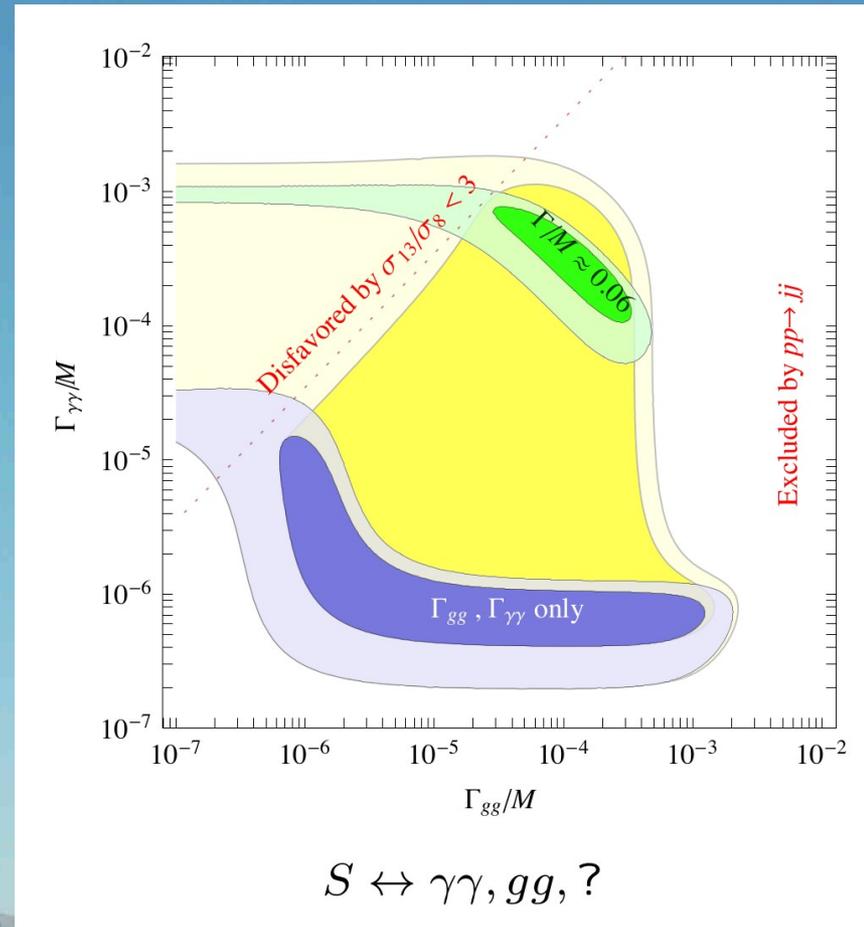
ATLAS prefers large width $\Gamma/M \sim 0.06$.

CMS prefers narrow width.

$\gamma\gamma$ not accompanied by hard extras.

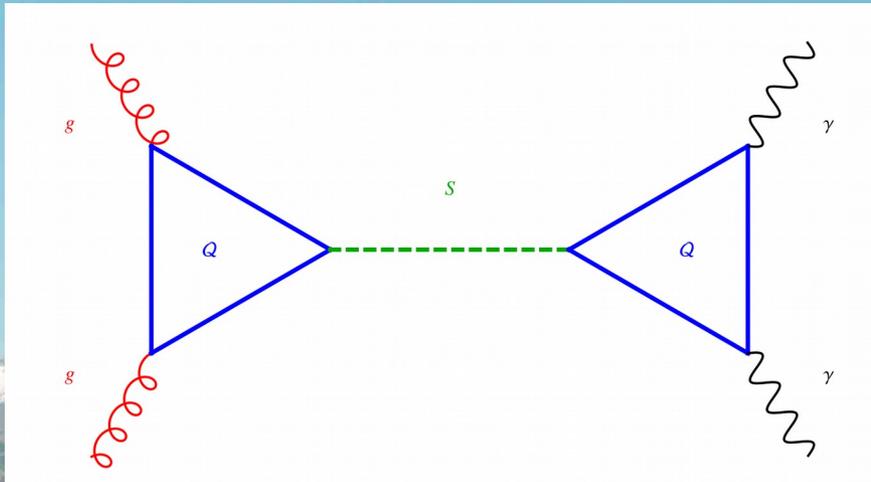
How can it be generated?

- The large enhancement from 8 to 13 TeV favours production via gg , $b\bar{b}$, $s\bar{s}$, $c\bar{c}$
- Assume gg production:



How can it be generated?

- The large enhancement from 8 to 13 TeV favours production via gg , $b\bar{b}$, $s\bar{s}$, $c\bar{c}$
- Assume gg production
- Easy to implement: new particles induce effective couplings at loop level (correlations with other channels)



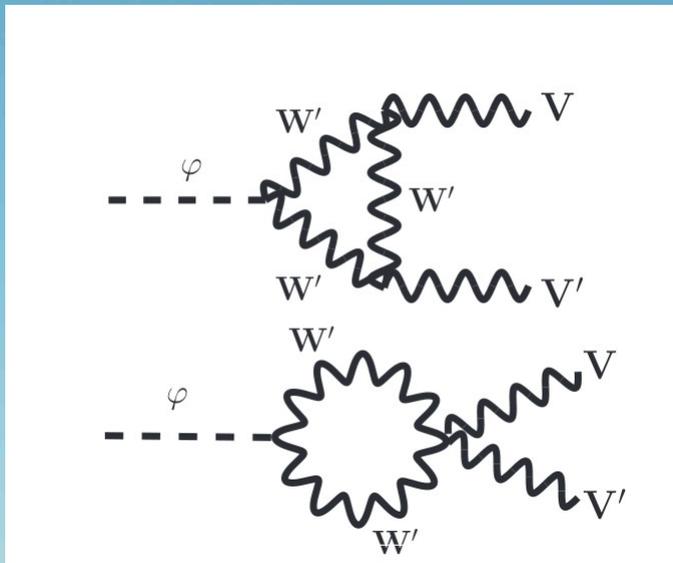
New vector-like quarks and leptons or new scalars normally used

New vectors also possible

How can it be generated?

- New vectors and the diphoton anomaly. The 750 GeV scalar can be the Higgs of a new broken gauge symmetry: the new vectors can induce the required couplings

Blas, JS, Vega-Morales '15



Example: color octet with electric charge 1 and order one coupling reproduces with observed excess (with narrow width)

How can it be generated?

- New vectors and the diphoton anomaly. The 750 GeV scalar can be the Higgs of a new broken gauge symmetry: the new vectors can induce the required couplings
- It might be even possible to reproduce other reported anomalies like the ~ 2 TeV diboson and the $t\bar{t}$ forward-backward asymmetry
- Large width difficult to generate at the loop level (but not new Landau poles from vectors)

Conclusions

- Naturalness is still a good guiding principle for new physics at the LHC
- Pressure from null experimental results motivate more baroque models: new approach to collider searches
 - Cancellations possible (expected)
 - Rich spectra with unexpected features (large mixing, non-conventional decay or production channels, ...)
- Reported anomalies have to be explained without contradicting other searches: diphoton is a good place for an anomaly to show up