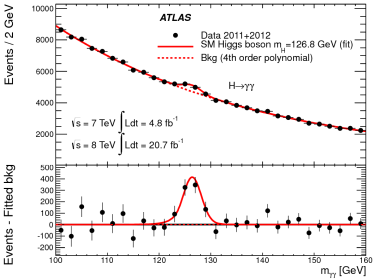
About the diphoton excess at ATLAS and CMS

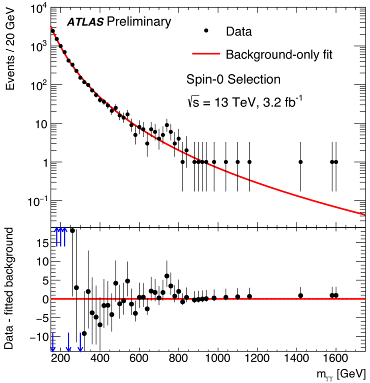
Florian Staub

CERN

General Seminar
INFN, 23rd June 2016


ATLAS
Data 2011+2012
SM Higgs boson m_H=126.8 GeV (fit)
Bkg (4th order polynomial)
H→γγ
√s = 7 TeV ∫Ldt = 4.8 fb^-1
√s = 8 TeV ∫Ldt = 20.7 fb^-1
Events / 2 GeV
Events - Fitted bkg
m_γγ [GeV]

2012


ATLAS Preliminary
Data
Background-only fit
Spin-0 Selection
√s = 13 TeV, 3.2 fb^-1
Events / 20 GeV
Data - fitted background
m_γγ [GeV]

2016

Outline

Experimental data

Proposed models

Summary

Data and Fits

Overall significance?

The local significance for both experiments is above 3σ each.

Overall significance?

The local significance for both experiments is above 3σ each.

There is no official combined analyses of the ATLAS and CMS data, but ...

- Matthew R. Buckley: 1601.04751
- Hans Peter Nilles, Martin Wolfgang Winkler: 1604.03598

Overall significance?

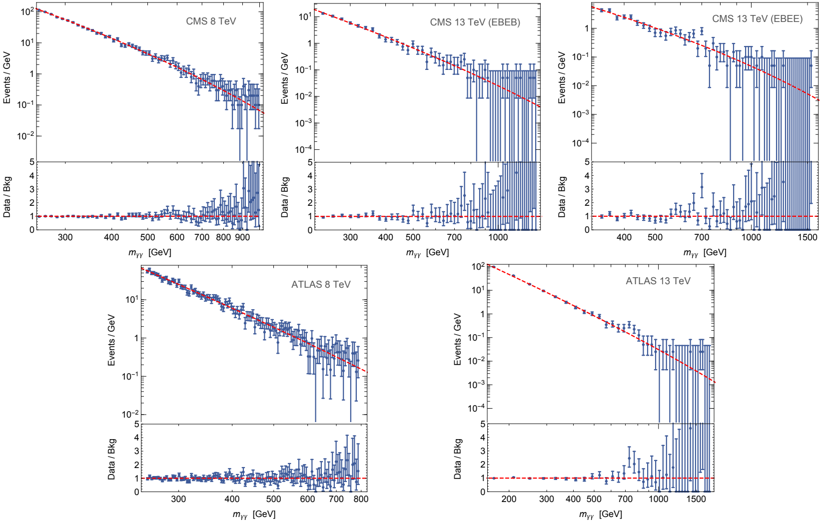
The local significance for both experiments is above 3σ each.

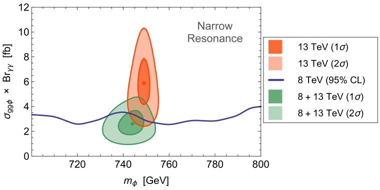
There is no official combined analyses of the ATLAS and CMS data, but . . .

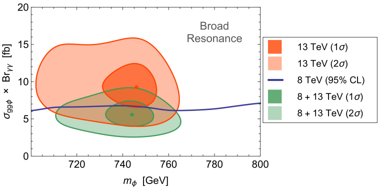
- Matthew R. Buckley: 1601.04751
- Hans Peter Nilles, Martin Wolfgang Winkler: 1604.03598

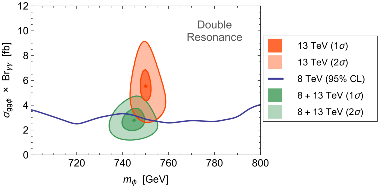
I present in the following the results of **1604.03598**.

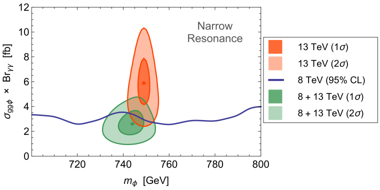
8 and 13 TeV data sets

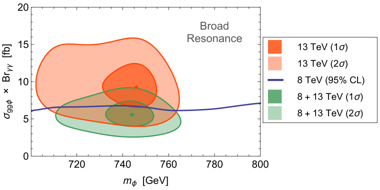


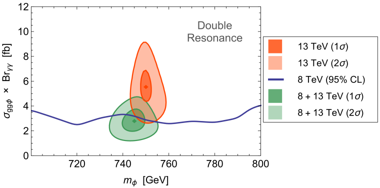

Narrow Resonance
13 TeV (1σ)
13 TeV (2σ)
8 TeV (95% CL)
8 + 13 TeV (1σ)
8 + 13 TeV (2σ)
$\sigma_{gg\phi} \times \mathrm{Br}_{\gamma\gamma}$ [fb]
m_ϕ [GeV]


Broad Resonance
13 TeV (1σ)
13 TeV (2σ)
8 TeV (95% CL)
8 + 13 TeV (1σ)
8 + 13 TeV (2σ)
$\sigma_{gg\phi} \times \mathrm{Br}_{\gamma\gamma}$ [fb]
m_ϕ [GeV]


Double Resonance
13 TeV (1σ)
13 TeV (2σ)
8 TeV (95% CL)
8 + 13 TeV (1σ)
8 + 13 TeV (2σ)
$\sigma_{gg\phi} \times \mathrm{Br}_{\gamma\gamma}$ [fb]
m_ϕ [GeV]







Resonance Type	m_ϕ	$\sigma_{gg\phi} \times \mathrm{Br}_{\gamma\gamma}$	Γ_ϕ	Significance
Narrow	744 GeV	2.6 fb	–	$3.3\,\sigma$
Broad (fixed width)	744 GeV	5.6 fb	40 GeV	$3.9\,\sigma$
Broad (free width)	745 GeV	6.9 fb	62 GeV	$4.0\,\sigma$
Double (fixed ratio)	745 GeV (705 GeV)	2.8 fb (1.3 fb)	–	$3.8\,\sigma$
Double (free ratio)	745 GeV (706 GeV)	2.5 fb (1.8 fb)	–	$3.9\,\sigma$

New physics or just a fluctuation?

New physics or just a fluctuation?

Why many people are very excited:

- Excess seen by both experiments at the same mass
- Consistent with 8 TeV data
- Clean channel

New physics or just a fluctuation?

Why many people are very excited:

- Excess seen by both experiments at the same mass
- Consistent with 8 TeV data
- Clean channel

However, ...

- Unexpected!
- ATLAS cross section needs to be interpreted as upwards fluctuation
- What's about ZZ and γZ?
- No 'nice' model?
- Why hasn't ATLAS presented an update at Moriond?

New physics or just a fluctuation?

Why many people are very excited:

- Excess seen by both experiments at the same mass
- Consistent with 8 TeV data
- Clean channel

However, . . .

- Unexpected!
- ATLAS cross section needs to be interpreted as upwards fluctuation
- What's about ZZ and γZ?
- No 'nice' model?
- Why hasn't ATLAS presented an update at Moriond?

Nevertheless, let's assume it is real. . .

Production

Disclaimer

I concentrate (mainly) on:

- the direct production of a 750 GeV particle (S) . . .
- . . . which decays promptly in two photons.

$\rightarrow$ Particle must have spin 0,2, . . .

Other possibilities:

- S produced by decay of heavier particles
- Three-body or cascade decays of S

8 vs 13 TeV

[Franceschini et al.,1512.04933]

There is a large increase in the production rate from 8 to 13 TeV:

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

8 vs 13 TeV

[Franceschini et al.,1512.04933]

There is a large increase in the production rate from 8 to 13 TeV:

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

The gain factors $r = \sigma_{13\text{TeV}}/\sigma_{8\text{TeV}}$ for different production mechanisms are

$r_{b\bar{b}}$	$r_{c\bar{c}}$	$r_{s\bar{s}}$	$r_{d\bar{d}}$	$r_{u\bar{u}}$	r_{gg}	$r_{\gamma\gamma}$
5.4	5.1	4.3	2.7	2.5	4.7	1.9

Preferred production mechanisms:

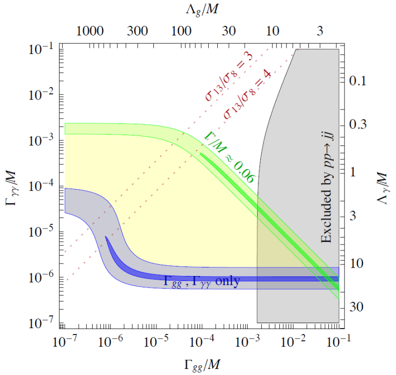
- Gluon fusion
- Coupling to heavy quarks

Pinning down the diphoton and digluon widths:

[Franceschini et al.,1512.04933]

For $\sigma_{\gamma\gamma} = 8$ fb @ 13 TeV

$$\frac{\Gamma\gamma\gamma}{M}\frac{\Gamma gg}{M} \simeq 1.1 \cdot 10^{-6}\frac{\Gamma}{M}$$

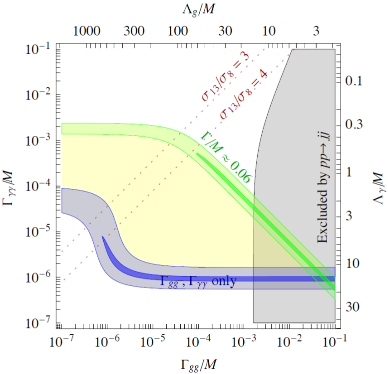


Pinning down the diphoton and digluon widths:

[Franceschini et al.,1512.04933]

For $\sigma_{\gamma\gamma} = 8$ fb @ 13 TeV

$$\frac{\Gamma\gamma\gamma}{M}\frac{\Gamma gg}{M} \simeq 1.1 \cdot 10^{-6}\frac{\Gamma}{M}$$



$\rightarrow$ Necessary diphoton widths: [for comparison: MSSM ($\tan\beta$=10) $\rightarrow \sim 10^{-9}$]

- Narrow width: $\Gamma\gamma\gamma/M \sim 10^{-6}$
- Broad width: $\Gamma\gamma\gamma/M \sim 10^{-4}$

Spin and width

A large width?

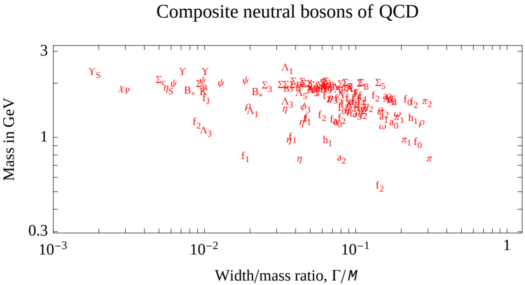
There is a small preference by ATLAS for a large width

- This width can't be explained by the decays into gg and $\gamma\gamma$

A large width?

There is a small preference by ATLAS for a large width

- This width can't be explained by the decays into gg and $\gamma\gamma$
- Possible explanations:
  - S is a composite particle

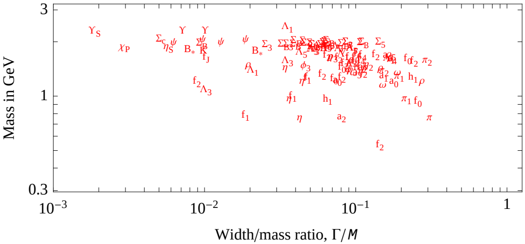


A large width?

There is a small preference by ATLAS for a large width

- This width can't be explained by the decays into gg and $\gamma\gamma$
- Possible explanations:
  - S is a composite particle

Composite neutral bosons of QCD

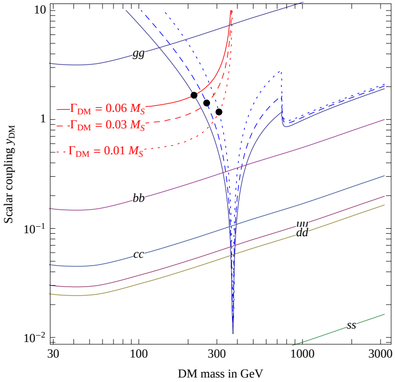


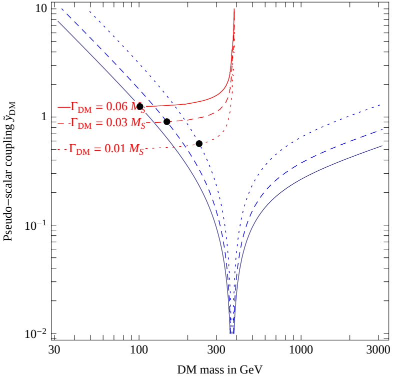
  - Invisible decays into dark matter

A large width via decays to dark matter?

S could be the portal to DM:

$$\mathcal{L} = \cdots + S\bar{\Psi}_{DM}(y + i\gamma_5\tilde{y})\Psi_{DM}$$





sold: $\Gamma/M = 0.6$, dashed: $\Gamma/M = 0.03$, dotted: $\Gamma/M = 0.01$

Spin 0 or 2?

No experimental preference so far . . .

Spin 0 or 2?

No experimental preference so far ...

... but a slight theoretical one: [Sanz,1603.05574],[Strumia,1605.09401]

- Spin 2 graviton predicts
  $\sigma(pp \to S \to e^+e^- + \mu^+\mu^-) = \sigma(pp \to S \to \gamma\gamma)$
- Glueball of new strong interaction: predicts usually a lighter spin-1 particle

Spin 0 or 2?

No experimental preference so far ...

... but a slight theoretical one: [Sanz,1603.05574],[Strumia,1605.09401]

- Spin 2 graviton predicts
  $\sigma(pp \to S \to e^+e^- + \mu^+\mu^-) = \sigma(pp \to S \to \gamma\gamma)$
- Glueball of new strong interaction: predicts usually a lighter spin-1 particle

Both conclusions could be evaded with some model building efforts

Constraints

Constraints on other decay modes

final state f	σ at $\sqrt{s} = 8$TeV observed	expected	implied bound on $\Gamma(S \to f)/\Gamma(S \to \gamma\gamma)_{\text{obs}}$
$e^+e^-, \mu^+\mu^-$	$<$ 1.2 fb	$<$ 1.2 fb	$< 0.6\ (r/5)$
$\tau^+\tau^-$	$<$ 12 fb	$<$ 15 fb	$< 6\ (r/5)$
$Z\gamma$	$<$ 11 fb	$<$ 11 fb	$< 6\ (r/5)$
ZZ	$<$ 12 fb	$<$ 20 fb	$< 6\ (r/5)$
Zh	$<$ 19 fb	$<$ 28 fb	$< 10\ (r/5)$
hh	$<$ 39 fb	$<$ 42 fb	$< 20\ (r/5)$
W^+W^-	$<$ 40 fb	$<$ 70 fb	$< 20\ (r/5)$
$t\bar{t}$	$<$ 450 fb	$<$ 600 fb	$< 300\ (r/5)$
invisible	$<$ 0.8 pb	-	$< 400\ (r/5)$
$b\bar{b}$	$<$1 pb	$<$ 1 pb	$< 500\ (r/5)$
jj	$<$ 2.5 pb	-	$< 1300\ (r/5)$

[Franceschini et al.,1512.04933]

Constraints on other decay modes

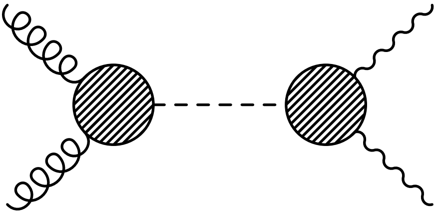
final state f	σ at $\sqrt{s} = 8$TeV observed	expected	implied bound on $\Gamma(S \to f)/\Gamma(S \to \gamma\gamma)_{\text{obs}}$
$e^+e^-, \mu^+\mu^-$	< 1.2 fb	< 1.2 fb	$< 0.6\ (r/5)$
$\tau^+\tau^-$	< 12 fb	< 15 fb	$< 6\ (r/5)$
$Z\gamma$	< 11 fb	< 11 fb	$< 6\ (r/5)$
ZZ	< 12 fb	< 20 fb	$< 6\ (r/5)$
Zh	< 19 fb	< 28 fb	$< 10\ (r/5)$
hh	< 39 fb	< 42 fb	$< 20\ (r/5)$
W^+W^-	< 40 fb	< 70 fb	$< 20\ (r/5)$
$t\bar{t}$	< 450 fb	< 600 fb	$< 300\ (r/5)$
invisible	< 0.8 pb	-	$< 400\ (r/5)$
$b\bar{b}$	<1 pb	< 1 pb	$< 500\ (r/5)$
jj	< 2.5 pb	-	$< 1300\ (r/5)$

[Franceschini et al.,1512.04933]

→ in particular ZZ/WW and hh are important (tree level decays)

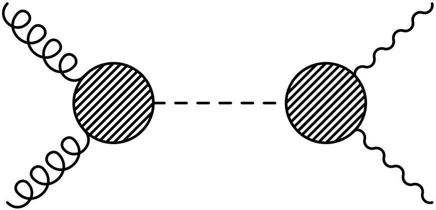
Constraints on a scalar resonance

Simplest idea to realise this excess:



Constraints on a scalar resonance

Simplest idea to realise this excess:

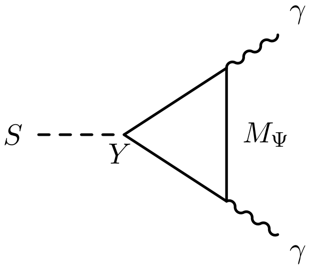


Is it possible to get $\sigma_{\gamma\gamma}$ sufficiently large via loop effects?

Constraints on fermion loops

Possibilities to increase the diphoton rate via fermion loops:

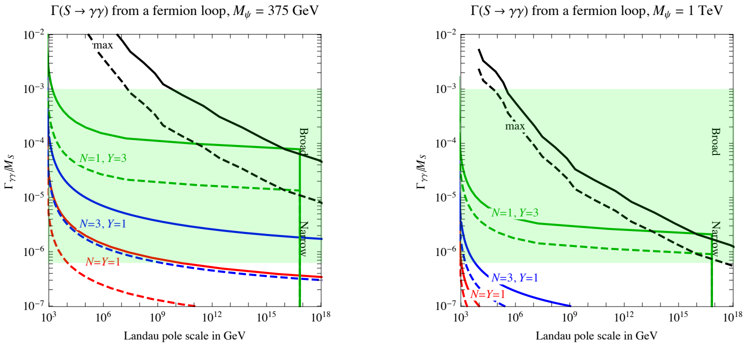
- Large coupling Y between fermions and scalar
- Large charge of particles in loop
- Large multiplicity of particles in loop



Constraints on fermion loops

Possibilities to increase the diphoton rate via fermion loops:

- Large coupling Y between fermions and scalar
- Large charge of particles in loop
- Large multiplicity of particles in loop



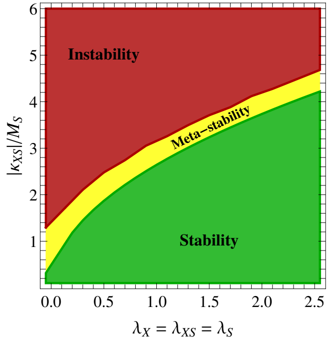
dashed: scalar, full: pseudo-scalar

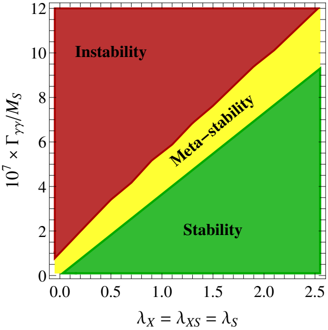
[Salvio,FS,Strumia,Urbano,1602.01460]

Constraints on scalar loops

Large cubic scalar couplings are constrained by vacuum stability

$$V(S,X) = \frac{M_S^2}{2}S^2 + M_X^2|X|^2 + \lambda_S S^4 + \lambda_{XS}S^2|X|^2 + \lambda_X|X|^4 + \frac{\kappa_S}{3}S^3 + \kappa_{XS}S|X|^2$$



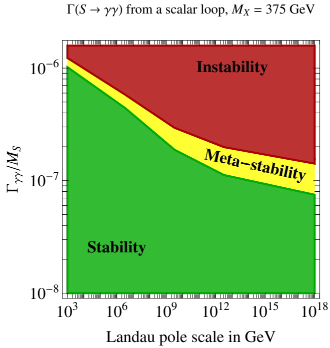


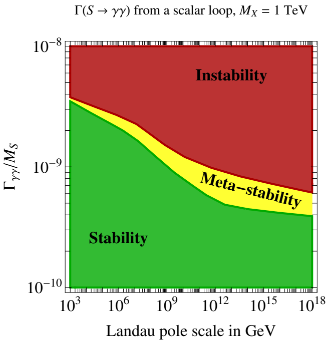
[Salvio,FS,Strumia,Urbano,1602.01460]

Constraints on scalar loops

Large cubic scalar couplings are constrained by vacuum stability

$$V(S,X) = \frac{M_S^2}{2}S^2 + M_X^2|X|^2 + \lambda_S S^4 + \lambda_{XS} S^2|X|^2 + \lambda_X|X|^4 + \frac{\kappa_S}{3}S^3 + \kappa_{XS} S|X|^2$$





[Salvio,FS,Strumia,Urbano,1602.01460]

The future?

Upcoming signals

If the excess is real, many more signals are going to appear

- $Z\gamma$
- ZZ, WW
- ...
- Associated production SW, SZ, $S\gamma$

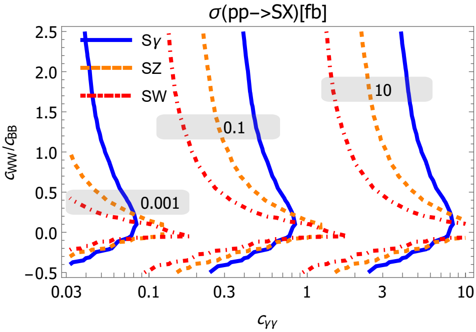
Upcoming signals

If the excess is real, many more signals are going to appear

- $Z\gamma$
- ZZ, WW
- $\dots$
- Associated production SW, SZ, $S\gamma$

$$\mathcal{L} = \frac{1}{2M} S\Big(g_3^2 (c_{gg} G^2 + \tilde{c}_{gg} G\tilde{G}) + g_2^2 (c_{WW} W^2 + \tilde{c}_{WW} W\tilde{W}) + g_1^2 (c_{BB} B^2 + \tilde{c}_{BB} B\tilde{B}) \Big).$$

[Chala,Grojean,Riembau,Vantalon,1604.02029]



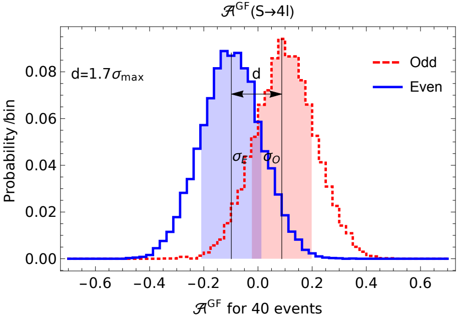
CP nature

The channels $S \to ZZ \to 4l$ or $2j2l$ and $S \to WW \to 2jl\not{E}_T$ can be used to pin down the CP nature

$$\mathcal{A}^{\text{GF}} = \frac{N(\theta^{\text{GF}} > \pi/4) - N(\theta^{\text{GF}} < \pi/4)}{N(\theta^{\text{GF}} > \pi/4) + N(\theta^{\text{GF}} < \pi/4)}$$

$$\theta = \arccos\left\{\frac{(p_1 \times p_2)\cdot(p_3 \times p_4)}{|p_1 \times p_2||p_3 \times p_4|}\right\}$$

[Chala,Grojean,Riembau,Vantalon,1604.02029]



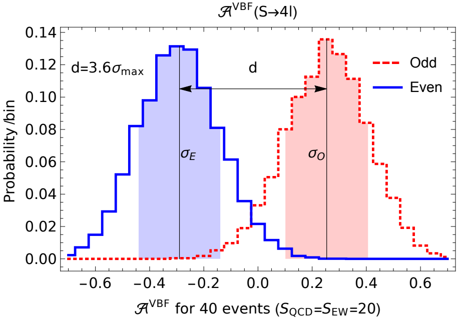
CP nature

The channels $S \to ZZ \to 4l$ or $2j2l$ and $S \to WW \to 2jl\not{E}_T$ can be used to pin down the CP nature

$$\mathcal{A}^{\text{GF}} = \frac{N(\theta^{\text{GF}} > \pi/4) - N(\theta^{\text{GF}} < \pi/4)}{N(\theta^{\text{GF}} > \pi/4) + N(\theta^{\text{GF}} < \pi/4)}$$

$$\theta = \arccos\left\{\frac{(p_1 \times p_2)\cdot(p_3 \times p_4)}{|p_1 \times p_2||p_3 \times p_4|}\right\}$$

[Chala,Grojean,Riembau,Vantalon,1604.02029]



Models

There are many ideas how to interpret that excess

- Weakly coupled models with scalar resonance (SUSY and non-SUSY)
- Bound states of fermions or scalars
- Composite / Strongly coupled models
- Extra-dimensions: 750 GeV as graviton, dilaton or radion
- Supersymmetry: Sgoldstino
- Axion-like models
- Radiative neutrino mass models
- ...

There are many ideas how to interpret that excess

- Weakly coupled models with scalar resonance (SUSY and non-SUSY)
- Bound states of fermions or scalars
- Composite / Strongly coupled models
- Extra-dimensions: 750 GeV as graviton, dilaton or radion
- Supersymmetry: Sgoldstino
- Axion-like models
- Radiative neutrino mass models
- ...

I concentrate in the following on a few weakly coupled models

Non-SUSY Models

Vector-like fermions

The simplest idea is to extent the SM by a singlet and vector-like fermions.

[Knapen et al.,1512.04928]

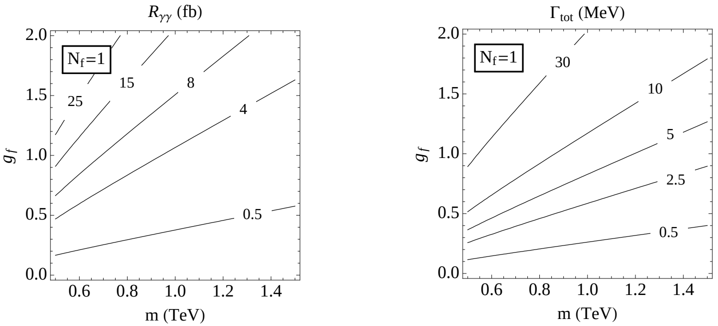
A collection of possibilities:

$SU(3)_C$	**3**	**3**	**3**	**3**	**3**	**3**	**3**	1	1	1	1	1	**3**
$SU(2)_L$	**2**	**3**	**2**	**3**	1	**2**	1	1	**2**	**3**	**2**	**3**	1
$U(1)_Y$	$\frac{7}{6}$	$\frac{2}{3}$	$-\frac{5}{6}$	$-\frac{1}{3}$	$\frac{2}{3}$	$\frac{1}{6}$	$-\frac{1}{3}$	1	$-\frac{3}{2}$	1	$-\frac{1}{2}$	0	$\frac{5}{3}$

Vector-like fermions

The simplest idea is to extent the SM by a singlet and vector-like fermions.

[Knapen et al.,1512.04928]



(for $(3,2)_{7/6}$)

Vector-like fermions

The simplest idea is to extent the SM by a singlet and vector-like fermions.

Similar extensions were proposed for Two-Higgs-Doublet-Models and Triplet models.

Vector-like fermions

The simplest idea is to extent the SM by a singlet and vector-like fermions.

Main constraints (in general):

- Perturbativity limits
- For non-vanishing $S-H$ mixing: limits from ZZ and WW searches
- When only using coloured fermions: limits from jj searches

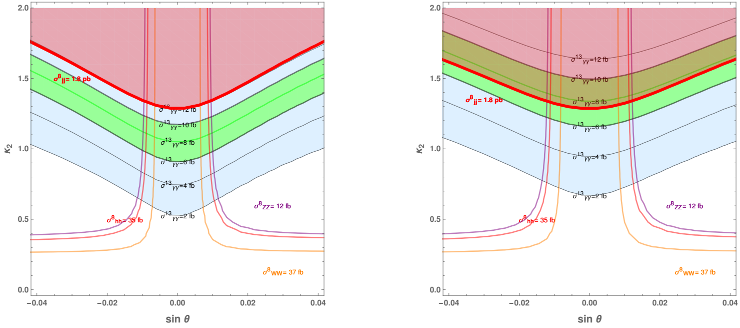
$\rightarrow$ see also the next example

Octet model

[Cao et al.,1512.06728],[FS et al., 1602.05581]

SM extended by gauge singlet S and Octet O $[(8,2)_{\frac{1}{2}}]$

$$V = \frac{1}{2} m_S^2 S^2 + \lambda_S S^4 + 2 m_O^2 \mathrm{Tr}(O^\dagger O) + \kappa_2 S^2 \mathrm{Tr}(O^\dagger O) + \dots$$



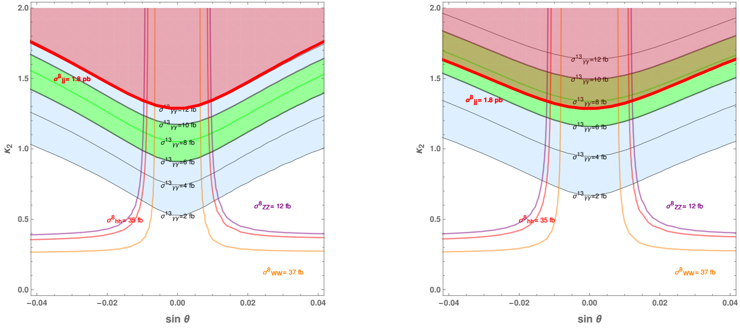
Θ:S-H mixing angle; left: LO, right: including higher order corrections

Octet model

[Cao et al.,1512.06728],[FS et al., 1602.05581]

SM extended by gauge singlet S and Octet O $[(8,2)_{\frac{1}{2}}]$

$$V = \frac{1}{2} m_S^2 S^2 + \lambda_S S^4 + 2 m_O^2 \mathrm{Tr}(O^\dagger O) + \kappa_2 S^2 \mathrm{Tr}(O^\dagger O) + \dots$$



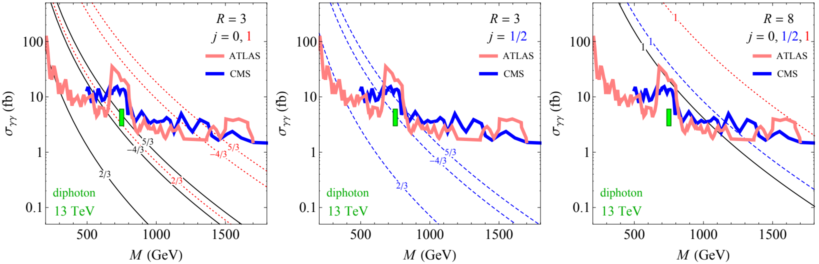
Θ:S-H mixing angle; left: LO, right: including higher order corrections

→ Higher order corrections are very important (but often not included)!

Bound states

S could be a bound state of two scalars or fermions with $m_P \sim 375$ GeV: [Kats,Strassler,1602.08819]

$$pp \to (PP) \to \gamma\gamma$$



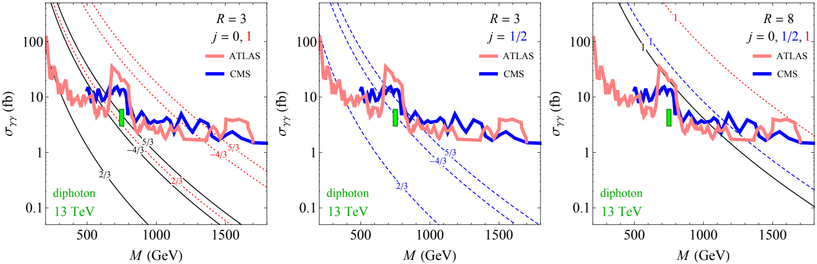
Possibilities to get correct $\sigma_{\gamma\gamma}$: colour triplet with

$Q = -\frac{4}{3}$ (fermion) or $\frac{5}{3}$ (scalar)

Bound states

S could be a bound state of two scalars or fermions with $m_P \sim 375$ GeV: [Kats,Strassler,1602.08819]

$$pp \to (PP) \to \gamma\gamma$$



Possibilities to get correct $\sigma_{\gamma\gamma}$: colour triplet with

$Q = -\frac{4}{3}$ (fermion) or $\frac{5}{3}$ (scalar)

→ Not present in 'standard' SM extensions.

SUSY Models

Sgoldstino

[Casas et al.,1512.07895],[Ding et al.,1602.00977]

The superpartner of the Goldstino couples to photons via

$$\mathcal{L} = \frac{M_{\tilde{\gamma}}}{2\sqrt{2}F}\mathrm{tr}F_{\mu\nu}\left(\Phi_S F^{\mu\nu} - \Phi_P \tilde{F}^{\mu\nu}\right) + \ldots$$

Sgoldstino

[Casas et al.,1512.07895],[Ding et al.,1602.00977]

The superpartner of the Goldstino couples to photons via

$$\mathcal{L} = \frac{M_{\tilde{\gamma}}}{2\sqrt{2}F}\text{tr}F_{\mu\nu}\left(\Phi_S F^{\mu\nu} - \Phi_P \tilde{F}^{\mu\nu}\right) + \dots$$

- $\rightarrow$ correlation between diphoton rate and SUSY mass spectrum.
- $\rightarrow$ gauge mediation with low messenger masses the most promising susy breaking mechanism

Sgoldstino

[Casas et al.,1512.07895],[Ding et al.,1602.00977]

The superpartner of the Goldstino couples to photons via

$$\mathcal{L} = \frac{M_{\tilde{\gamma}}}{2\sqrt{2}F} \mathrm{tr} F_{\mu\nu} \left(\Phi_S F^{\mu\nu} - \Phi_P \tilde{F}^{\mu\nu} \right) + \dots$$

$\rightarrow$ correlation between diphoton rate and SUSY mass spectrum.

$\rightarrow$ gauge mediation with low messenger masses the most promising susy breaking mechanism

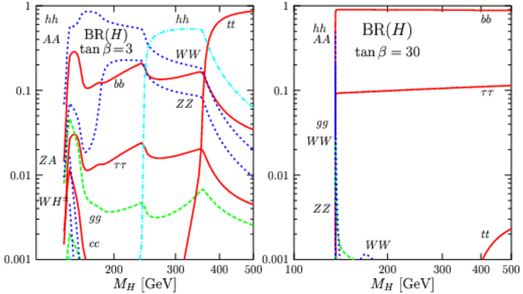
However,. . .

- . . . very difficult to build realistic models of SUSY breaking which explain the excess and which are in agreement with all SUSY limits. [Bardhan et al, 1603.05251]
- . . . in extreme regions of parameter space, it might be possible [Baratella et al, 1603.05682]

The MSSM

It is not possible to explain this excess in the MSSM:

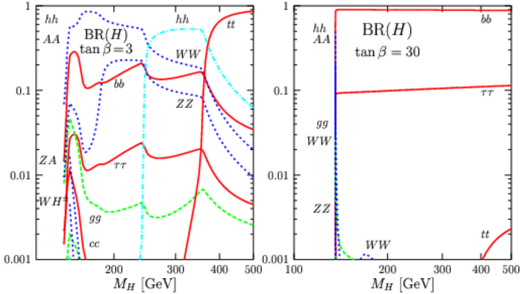
- The diphoton rate is usually too small



The MSSM

It is not possible to explain this excess in the MSSM:

- The diphoton rate is usually too small



- Idea to increase the rate via large cubic couplings to 375 GeV stops [Djouadi, Pilaftsis,1605.01040]

$\rightarrow$ in conflict with vacuum stability!

The MSSM with stop bound states

Possible to explain the excess via stoponium in the MSSM?

[Choudhury,Ghosh,1605.00013]

Main *assumption*: huge A-terms $\rightarrow$ large binding energy
$\rightarrow$ large uncertainty on vacuum stability and production rate

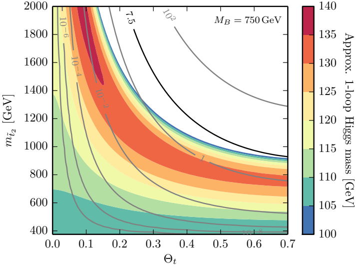
The MSSM with stop bound states

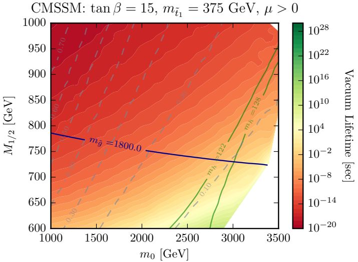
Possible to explain the excess via stoponium in the MSSM?

[Choudhury,Ghosh,1605.00013]

Main *assumption*: huge A-terms $\rightarrow$ large binding energy
$\rightarrow$ large uncertainty on vacuum stability and production rate

However, the binding energy is small in interesting regions!





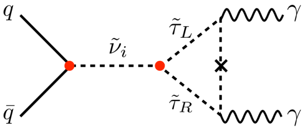
[Dreiner,Krauss,Opferkuch,FS,1606.XXXXX]

$\rightarrow$ Scenario is definitively ruled out!

The MSSM with RpV

With broken R-parity new contributions are possible:

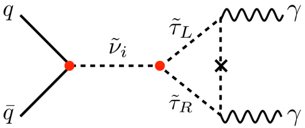
[Allanach et al.,1512.07645],[Ding et al.,1512.06560]



The MSSM with RpV

With broken R-parity new contributions are possible:

[Allanach et al.,1512.07645],[Ding et al.,1512.06560]



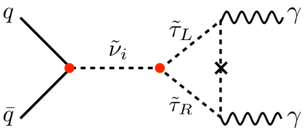
$\rightarrow$ Again, highly disfavoured by vacuum stability constraints!

- Needs maximal left-right mixing in stau sector
- Superposition of several resonances with tiny widths necessary

The MSSM with RpV

With broken R-parity new contributions are possible:

[Allanach et al.,1512.07645],[Ding et al.,1512.06560]

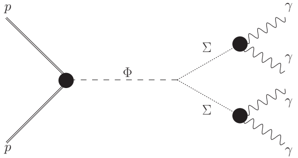


→ Again, highly disfavoured by vacuum stability constraints!

- Needs maximal left-right mixing in stau sector
- Superposition of several resonances with tiny widths necessary
- Even then the life-time is borderline

The NMSSM

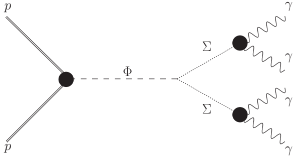
The diphoton excess could be explained via very light pseudo-scalars, e.g.: [Ellwanger,Hugonie,1602.03344],[Domingo et al.,1602.07691]



Proposed scenarios:
$M_A \sim$ 135, 210 or 510 MeV

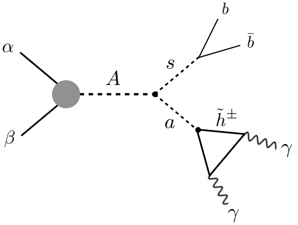
The NMSSM

The diphoton excess could be explained via very light pseudo-scalars, e.g.: [Ellwanger,Hugonie,1602.03344],[Domingo et al.,1602.07691]



Proposed scenarios:
$M_A \sim$ 135, 210 or 510 MeV

Alternatively [Badziak et al.,1603.02203]



with
$M_A \sim 850$ GeV, $M_a \sim 750$ GeV, $M_s \sim 60$ GeV

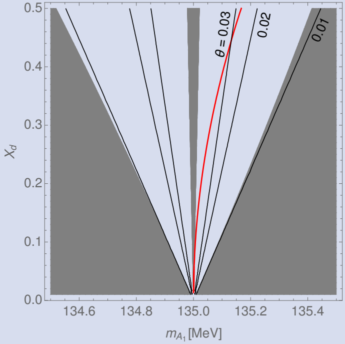
The NMSSM

The diphoton excess could be explained via very light pseudo-scalars, e.g.: [Ellwanger,Hugonie,1602.03344],[Domingo et al.,1602.07691]

Tuning

Large fine-tuning in particular for the first case:

- no symmetry to keep M_A tiny
- large tuning in mass needed.



γ

SUSY models with vector-like states

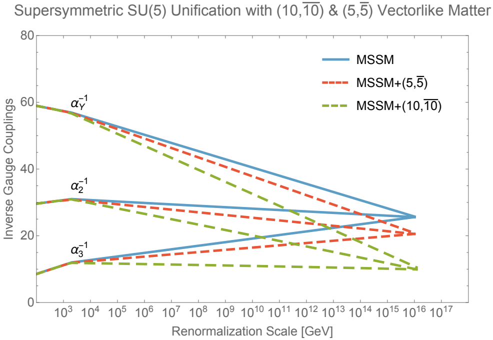
A widely considered idea is to extent the NMSSM by pairs of $SU(5)$ multiplets: [1512.07904,1601.00866,1604.03598,1604.07838,1605.03585...]

$$\mathbf{5} : d, l \qquad \mathbf{10} : e, q, u$$

SUSY models with vector-like states

A widely considered idea is to extent the NMSSM by pairs of $SU(5)$ multiplets: [1512.07904,1601.00866,1604.03598,1604.07838,1605.03585...]

$$\mathbf{5} : d, l \qquad \mathbf{10} : e, q, u$$



[Dutta et al.,1601.00866]

SUSY models with vector-like states

The superpotential is

$$W = \mu \hat{H}_u \hat{H}_d + \lambda \hat{S} \hat{H}_u \hat{H}_d + \Lambda \hat{S} \phi \bar{\phi} + M_\phi \phi \bar{\phi} + W_Y + W_{Y'} + W_S$$

Good:

- Consistent with gauge coupling unification
- Production cross section large enough for Λ O(1)
- Can help to increase the Higgs mass via new loops
- Possible connection to FermiLAT Excess

SUSY models with vector-like states

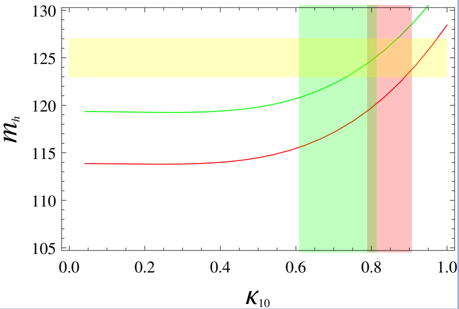
The superpotential is

$$W = \mu \hat{H}_u \hat{H}_d + \lambda \hat{S} \hat{H}_u \hat{H}_d + \Lambda \hat{S} \phi \bar{\phi} + M_\phi \phi \bar{\phi} + W_Y + W_{Y'} + W_S$$

Good

-
- 1)
- ops
-

New loops via $\kappa_{10} U_{10} Q_{10} H_u$:



band: one-loop, lines: two-loop; green(red): large(small) stop mixing

SUSY models with vector-like states

The superpotential is

$$W = \mu \hat{H}_u \hat{H}_d + \lambda \hat{S} \hat{H}_u \hat{H}_d + \Lambda \hat{S} \phi \bar{\phi} + M_\phi \phi \bar{\phi} + W_Y + W_{Y'} + W_S$$

Good:

- Consistent with gauge coupling unification
- Production cross section large enough for Λ O(1)
- Can help to increase the Higgs mass via new loops
- Possible connection to FermiLAT Excess

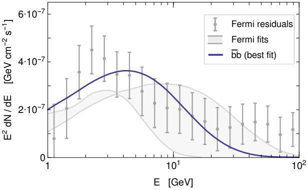
Not so good:

- Vector-like states added *ad hoc*
- λ must be tuned to small values (no tree-level enhanced Higgs mass)

Connection to dark matter

[Krauss,Opferkuch,FS,Winkler,1605.05327]

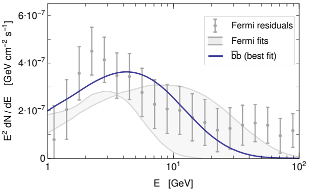
FermiLAT sees a peak in the γ spectrum $\rightarrow$ Hooperon?

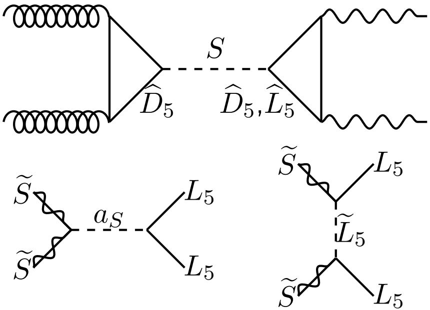


Connection to dark matter

[Krauss,Opferkuch,FS,Winkler,1605.05327]

FermiLAT sees a peak in the γ spectrum $\rightarrow$ Hooperon?





Possible origin:

- The 750 GeV excess and the Hooperon are superpartnerns
- DM annihilation: $\tilde{S}\tilde{S} \rightarrow L_5 \bar{L}_5 \rightarrow (\tau^+ A)(\tau^- A)$

Other (SUSY) models

Even more SUSY scenarios were already studied:

- Models with Dirac gauginos
- Models with extra $U(1)$ gauge group
- E_6 models
- ...

Model database and tools

[FS et al., 1602.05581]

If you want to make your own study:

SARAH model files to implement more than 40 of the proposed models in

- MadGraph
- CalcHep, MicrOmegas
- WHIZARD
- SPheno
- FlexibleSUSY
- ...

are available at:

http://sarah.hepforge.org/

Summary

The excess seen by ATLAS and CMS has triggered a lot of excitement

- Detailed analyses of the excess have been performed
- Already future strategies to pin down the properties of the potential particle were developed
- Many models have been proposed to explain the excess, but a more careful analysis renders them often questionable

We will know soon if it has been worth all the efforts ...