Pure NMSSM interpretation of 750 GeV diphoton excess

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based on: M. Badziak, M.O. S. Pokorski and K. Sakurai arXiv:1603.02203

Outline

- Introduction: 750 GeV $\gamma\gamma$ excess at 8 and 13 TeV
- Interpretation as cascade decay of heavier particle
- Realization in NMSSM
  - production
  - branching ratios of decays
  - constraints on masses and mixing angles
- Comparison with experimental data
  - some numerical examples
- Conclusions

Introduction: 750 GeV $\gamma\gamma$ excess at 8 and 13 TeV

$\sqrt{s} = 13$ TeV

- Excess in $\gamma\gamma$ channel with $m_{\gamma\gamma} \approx 750$ GeV observed by ATLAS and CMS
- Local significance $\gtrsim 3\sigma$

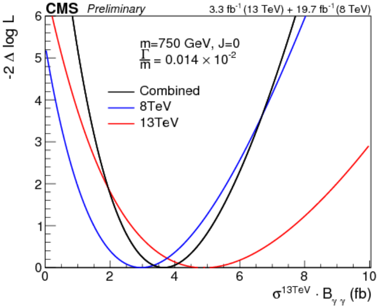
$\sqrt{s} = 8$ TeV (reanalyzed)

- Some excess in $\gamma\gamma$ channel with $m_{\gamma\gamma} \approx 750$ GeV reported by CMS and ATLAS
- Local significance $\sim 2\sigma$

The most popular explanation:
production and decay of a resonance with $m \approx 750$ GeV

Assuming dominant production mechanism (usually gluon fusion) one can compare the 8 TeV and 13 TeV data

Introduction: 750 GeV $\gamma\gamma$ excess at 8 and 13 TeV



CMS: CMS PAS EXO-16-018

8 TeV date rescaled to 13 TeV (assuming the gluon fusion as the main production mechanism)

Central value of $\sigma \cdot \mathrm{BR}_{\gamma\gamma}$ for 8 TeV smaller than that for 13 TeV data

Agreement within 1σ

ATLAS: ATLAS-CONF-2016-018

- $\sigma \cdot \mathrm{BR}_{\gamma\gamma}$ smaller for 8 TeV, bigger for 13 TeV (as compared to CMS)
- no detailed analysis for a narrow resonance
- difference seems to be more than 2σ

Franceschini et al. arXiv:1604.06446

Interpretation as cascade decay of heavier particle

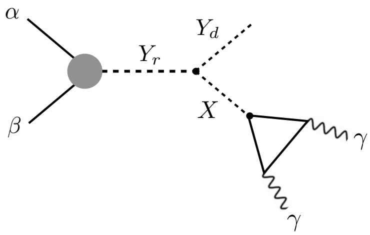
The most popular interpretation

- production and decay of a 750 GeV particle
  - increasing production (gg fusion) $\Rightarrow$ smaller $\mathrm{BR}_{\gamma\gamma}$
- extra vector-like particles are necessary

We investigate much less popular setup

- production of a heavier particle Y_r
- cascade decay to $\gamma\gamma$ via a 750 GeV particle X
  - production of Y_r may be independent of decays of X
  - 13 TeV production cross section of Y_r more enhanced with respect to 8 TeV (as compared to 750 GeV particle)
- use vector-like particles already present in a know model

Interpretation as cascade decay of heavier particle



α, β – initial state partons

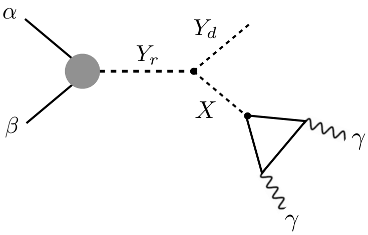
Y_r – particle heavier than 750 GeV

X – 750 GeV particle

Y_d – product of Y_r decay

loop – of vector-like particles

Interpretation as cascade decay of heavier particle



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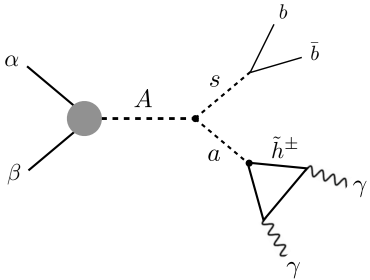
All the necessary ingredients are present in NMSSM

Realization in NMSSM



α, β – initial state partons

A – doublet-dominated pseudoscalar

a – singlet-dominated pseudoscalar

s – singlet-dominated scalar

$\tilde{h}^{\pm}$ – charginos

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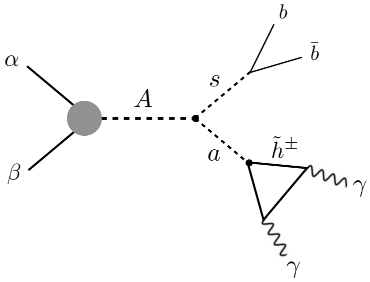

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$Y_d = h$ disfavoured:
Aha coupling $\Rightarrow$ A-a mixing $\Rightarrow$ suppression of $\mathrm{BR}(a \to \gamma\gamma)$

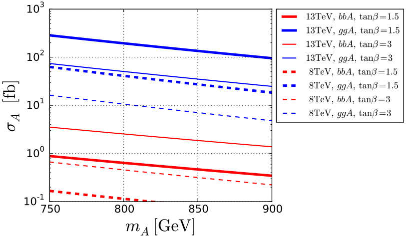
Y_d is not a pure s
$Y_d \approx s$ decays mainly to $b\bar{b}$ due to mixing with H

Different NMSSM scenario: $pp \to \Phi \to 2(\Sigma \to \gamma\gamma)$ 1602.03344, 1602.07691

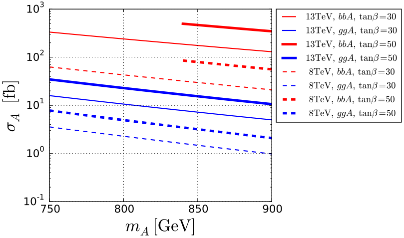
$$(\sigma \cdot \mathrm{BR}_{\gamma\gamma})^{\mathrm{signal}} \equiv \sigma(pp \to A) \cdot \mathrm{BR}(A \to sa) \cdot \mathrm{BR}(a \to \gamma\gamma)$$

Production of A (calculated using `SusHi v.1.5.0`) dominated by:

gg fusion at low $\tan\beta$



$b\bar{b}$ for large $\tan\beta$



Realization in NMSSM: decays

a decays into gauge bosons via the higgsino loop:

$\mathrm{BR}(a \to W^+W^-) \approx 0.65$ $\mathrm{BR}(a \to ZZ) \approx 0.23$
$\mathrm{BR}(a \to \gamma Z) \approx 0.05$ $\mathrm{BR}(a \to \gamma\gamma) \approx 0.07$

We need substantial $\mathrm{BR}(A \to as)$

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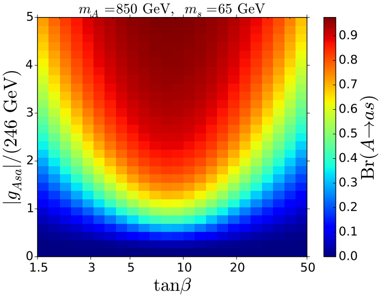

$\mathcal{L} \supset g_{Asa} Asa$

$A \to sa$ decay mode competes:
with $A \to b\bar{b}$ for large $\tan\beta$;
with $A \to t\bar{t}$ for small $\tan\beta$.

Decays modes into gauge bosons are highly suppressed because A is a pseudoscalar (CP).

Production of A prefers small and large values of $\tan\beta$
Decays of A prefer intermediate values of $\tan\beta$

Realization in NMSSM: masses and mixing angles

Constraints on the NMSSM parameters:

- singlet-dominated pseudoscalar $m_a \approx 750$ GeV
- light charginos: $m_{\tilde{h}^\pm} \approx 375$ GeV
  - $m_{\tilde{h}^\pm} > \frac{1}{2} m_a$ to avoid $a \to \tilde{h}^+ \tilde{h}^-$ decays
- light singlet-dominated scalar: $m_s \approx 65$ GeV
  - $m_s > \frac{1}{2} m_h$ to avoid $h \to ss$ decays
- 815 GeV $\lesssim m_A \lesssim$ 875 GeV
  - $A \to sa$ allowed but $A \to ha$ forbidden
- small A-a mixing
  - to suppress $a \to f\bar{f}$ decays
- small h-s mixing
  - LEP constraints on scalars with $m_s \sim 65$ GeV
- some H-s mixing
  - to suppress $\mathrm{BR}(s \to \gamma\gamma)$

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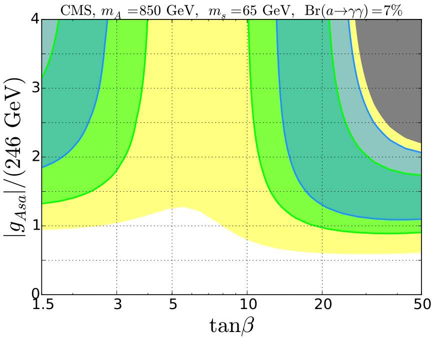
Strong enough $\gamma\gamma$ signal may be obtained in general NMSSM but for quite big values of λ and κ

$$W = W_{\mathrm{MSSM}} + \lambda S H_u H_d + \xi_F S + \frac{1}{2}\mu' S^2 + \frac{\kappa}{3} S^3$$

Comparison with experimental data



- 1σ region at 13 TeV
- 1σ region at 8 TeV
- 2σ region at 13 TeV
- 2σ excluded at 8 TeV

Neglecting h-s and A-a mixing: $|g_{Asa}/v_{SM}| = |\cos\theta_{Hs}\lambda\kappa|$

For 1σ (2σ) agreement with CMS data one needs:
$|\cos\theta_{Hs}\lambda\kappa| \gtrsim 2$ **(1) for small $\tan\beta$**
$|\cos\theta_{Hs}\lambda\kappa| \gtrsim 1$ **(0.6) for large $\tan\beta$**

Necessary values of λ and κ lead to a Landau pole only 2-3 orders of magnitude above the weak scale

Comparison with experimental data

Loop corrections to the SM-like Higgs mass may be very large for large values of λ and κ.

For example: $\Delta^{\rm loop} m_h \approx -20$ GeV for $\lambda = \kappa = 0.5$

Ellwanger, Hugonie hep-ph/0504269

In our case soft terms are not fixed at some values
but are chosen to (strongly) suppress h-s and A-a mixing.

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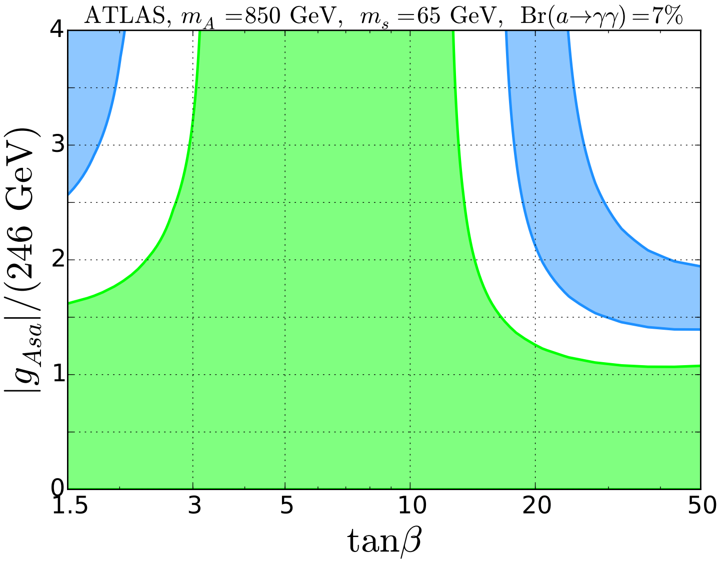
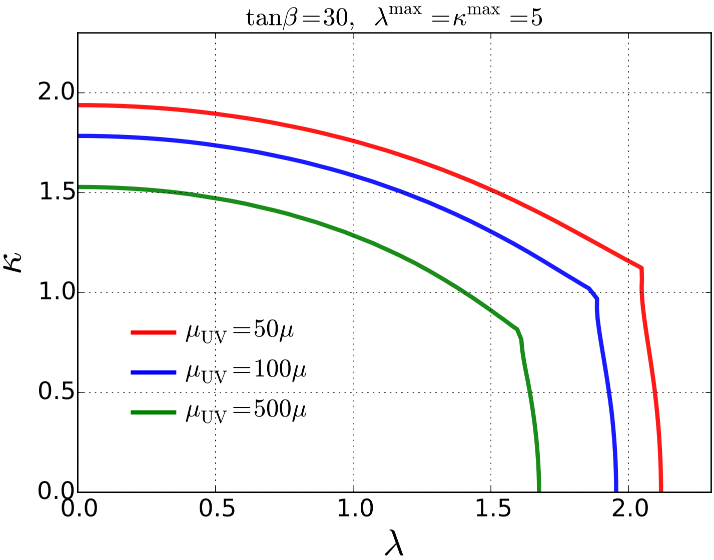
$\tan\beta$	$\lvert g_{Asa} \rvert$	λ	κ	A_λ	μ'	$\sin 2\theta_{Hs}$	$\widetilde{m}_h$
2	2.1	1.40	−1.51	390	1190	−0.30	209
2	1.4	0.69	−2.03	410	2630	−0.10	112
2	1.0	0.80	−1.26	420	1600	−0.18	125
2	1.0	0.68	−1.48	410	2050	−0.14	110
7	1.4	1.04	−1.51	870	1960	−0.80	110
20	1.3	0.80	−1.86	1290	2930	−0.94	97
20	1.0	0.68	1.77	1240	−690	−0.94	95
20	0.6	0.53	1.47	1780	−310	−0.98	92

Conclusions

- Pure NMSSM can explain the observed $\gamma\gamma$ signal at $m_{\gamma\gamma} \simeq 750$ GeV as a decay of a single particle into $\gamma\gamma$ pair
- Mechanism:
  - production of doublet-dominated pseudoscalar A
  - decay of A to singlet-dominated scalar s and pseudoscalar a
  - decay of a to $\gamma\gamma$ via chargino loop
  - $m_a \approx 750$ GeV, $m_A \in (815 \div 875)$ GeV
  - large values of $\tan\beta$ favoured over small $\tan\beta$
- Advantages:
  - no new particles necessary
  - production and decays are independent
  - stronger enhancement of production at 13 as compared to 8 TeV
- Price:
  - certain fine tuning of the parameters
  - large values of λ and $\kappa \Rightarrow$ relatively low UV cut-of (~ 100 TeV)
- Experimental signatures
  - fixed ratios of di-boson signals at 750 GeV
  - b-quark jets from relatively light s decays
- Waiting for new results ...

Backup


ATLAS, m_A =850 GeV, m_s =65 GeV, Br($a\to\gamma\gamma$)=7%
$|g_{Asa}|/(246\ \mathrm{GeV})$
4
3
2
1
0
1.5
3
5
10
20
50
$\tan\beta$


$\tan\beta = 30, \quad \lambda^{\max} = \kappa^{\max} = 5$
2.0
1.5
1.0
0.5
0.0
κ
0.0
0.5
1.0
1.5
2.0
λ
$\mu_{\rm UV} = 50\mu$
$\mu_{\rm UV} = 100\mu$
$\mu_{\rm UV} = 500\mu$