Possible 750 GeV diphoton signal via light pseudoscalars

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with C. Hugonie, arXiv:1602.03344,

see also F. Domingo et al., arXiv:1602.07691

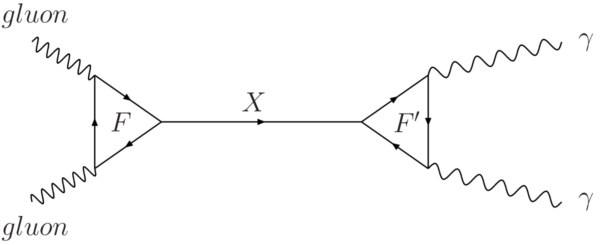
Data ($\lesssim$ Moriond 2016):

- ATLAS at 13 TeV, 710 GeV $< M_{\gamma\gamma} <$ 790 GeV (two bins):
  21 events vs. 11.3 expected; local excess 3.9 σ (2.0 σ incl. LLE);
  compatible with 8 TeV at the 1.2 σ level (assuming ggF)

- CMS at 13 TeV, 750 GeV $< M_{\gamma\gamma} <$ 770 GeV (one bin):
  11 events vs. 5.4 expected; local excess 2.8 σ (~ 1 σ incl. LLE);
  combined with 8 TeV: local excess 3.4 σ (1.6 σ incl. LLE)

- Signal cross sections of $\sim 3 - 8$ fb would explain the excesses

"Standard" interpretation:



— X: Scalar or pseudoscalar (possibly composite) with $M_X \sim 750$ GeV

— Coupling to gluons through loops of coloured fermions F

— Coupling to photons through loops of charged fermions F' ($\sim F$?)

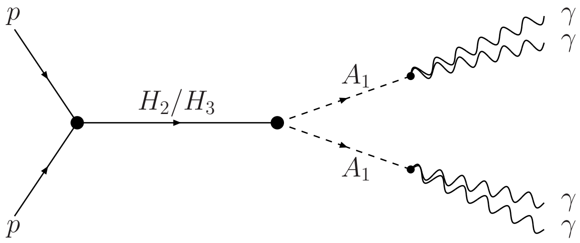
— Possibly a large width ($\gtrsim$ a few GeV) in order to explain the ATLAS data

Challenges:

- Need large (loop induced) production cross section
  $\rightarrow$ need large ($\sim$ non-perturbative) XFF Yukawa coupling
- Need large (loop induced) width into $\gamma\gamma$
  $\rightarrow$ need large ($\sim$ non-perturbative) $XF'F'$ Yukawa coupling
- Tree level decays of X must be (practically) forbidden, otherwise the loop induced decay into $\gamma\gamma$ would have a too small branching fraction
  $\rightarrow$ X must not couple to Standard Model fermions (or Higgs), the new fermions F (F') must be heavier than $M_X/2 \sim 375$ GeV
- A large width into $\gamma\gamma$ is tough to get...
- $\gtrsim 200$ BSM scenarios of this type... (more than events)

Alternative scenario with light pseudoscalars A_1:

(S. Knapen et al., P. Agrawal et al., J. Chang et al., ...)



Viable if $M_{A_1} \lesssim 800$ MeV; then the photons from A_1 decays are sufficiently collimated such that they appear (mostly) as a single photon in the electromagnetic calorimeters

Constraints on resonance(s) $H_{(i)}$ at ≈ 750 GeV:

- Sufficient production cross section in ggF or ass. prod. with b-quarks
- Large branching fraction into $A_1 A_1$

Constraints on a light pseudoscalar A_1 below ≈ 800 MeV:

- Not ruled out by low energy experiments
- Large branching fraction into $\gamma\gamma$
- Decay length $\lesssim 1$ m, preferably shorter

A concrete scenario: the NMSSM

featuring 3 scalars $H_{1,2,3}$ and two pseudoscalars $A_{1,2}$

Two candidates for scalar(s) H_2/H_3 at ≈ 750 GeV:
(with $H_1 =$ SM-Higgs at 125 GeV)

— the "MSSM-like" scalar H with potentially large production cross section via bbH if $\tan\beta \gtrsim 10$

— the singlet-like scalar H_S with potentially large branching fraction into singlet-like $A_1 A_1$ (A_2 is the MSSM-like pseudoscalar with $M_{A_2} \sim M_H$)

$\longrightarrow$ Best solution: both scalars have masses of ≈ 750 GeV,
H and H_S mix strongly and form H_2/H_3;
two nearby narrow states can imitate a large width as seen by ATLAS

A light pseudoscalar A_1 can be a (pseudo-) Goldstone boson of an R-symmetry
($\leftrightarrow$ small trilinear couplings A_λ, A_κ in the scalar potential);

Impossible in the MSSM where the μ-term breaks R-symmetry;
in the NMSSM, μ is replaced by the vev of a singlet field S
$\longrightarrow$ a (weakly broken) R-symmetry is possible

But: Broken by radiative corrections $\sim A_{top}$, gaugino masses
$\longrightarrow$ Tuning is still required for $M_{A_1} \lesssim 800$ MeV

Possible A_1 masses satisfying the above constraints:

(1) $M_{A_1} \sim M_{\pi^0} \sim 135$ MeV (Domingo et al., arXiv:1602.07691):

— A_1 mixes with π^0, hence A_1 decays with a similar width (short decay length) into $\gamma\gamma$; calculable using PCAC

Heavier A_1: 135 MeV $< M_{A_1} < 2m_\mu$:

— Susy loops generate flavour changing couplings of the extra (MSSM-like) Higgs bosons, hence also for A_1 (through mixing with the MSSM-like A_2)

$\rightarrow$ dangerous rare decays $K^\pm \to \pi^\pm e^+ e^-$ (less constraining: $B^\pm \to K^\pm e^+ e^-$) unless the soft Susy breaking terms are chosen such that contributions to flavour changing couplings cancel, which is possible (see arXiv:1602.07691)

— A_1 decays dominantly into e^+e^- with a decay length $\gtrsim 40$ m $\longrightarrow$ useless

(2) $M_{A_1} \lesssim 2m_\mu \sim 211$ MeV (U.E., C. Hugonie, arXiv:1602.03344):

— The muon loop induced BR into $\gamma\gamma$ is enhanced up to $\sim 75\%$ if M_{A_1} is just below the threshold (see A. Bharucha et al., arXiv:1603.04464)

— The decay length is reduced to 2–5 m, but the production cross section can be large enough such that enough $A_1 \to \gamma\gamma$ decays take place before the EM calorimeter

— Soft Susy breaking terms have to be chosen such that flavour changing couplings are cancelled

$M_{A_1} \gtrsim 500$ MeV: Constraints from rare K decays disappear

(3) $M_{A_1} \sim 510$ MeV (U.E., C. Hugonie, arXiv:1602.03344):

— At the parton level, the dominant decays of A_1 are into $s\bar{s}$ and gluons

— But: one is still in the nonperturbative regime of QCD
Best guess: $s\bar{s}$ and $F\widetilde{F}_{(QCD)}$ act as interpolating fields;
these are part of the η wave function in Fock space ($M_\eta \sim 548$ MeV),
hence A_1 decays like the η meson:
$BR(\eta \to \gamma\gamma) \sim 39\%$, $BR(\eta \to 3\pi^0) \sim 33\%$, $BR(\eta \to \pi^+\pi^-\pi^0) \sim 23\%$

$\to$ $BR(A_1 \to \gamma\gamma) \sim 39\%$, $BR(A_1 \to 3\pi^0 \to 6\gamma) \sim 33\%$
with a decay length below 1 mm (?to be confirmed?)

— Dominant constraint: Now from searches for $\Upsilon(1S) \to \gamma\,\eta$ decays by CLEO
where no events were seen
(but 2 events for $M_{\pi^+\pi^-\pi^0} \sim 510$ MeV in the $\eta \to \pi^+\pi^-\pi^0$ search channel)
$\to$ constraints on the coupling $A_1 b\bar{b}$;
if too large, CLEO would have observed $\Upsilon(1S) \to \gamma\, A_1 \to 3\pi^0$ decays

— These constrain the $BR(H_{2,3} \to A_1 A_1)$, still:
a signal cross section up to 6.7 fb is possible

(4) $M_{A_1} \sim M_\eta \sim 550$ MeV (U.E., C. Hugonie, arXiv:1602.03344):

— A_1 mixes strongly with the η meson, its corresponding branching fractions are no longer educated guesses (calculable using PCAC)

— But: Constraints from CLEO from unseen $\Upsilon(1S) \to \gamma\, A_1$ decays are somewhat stronger, still:

a signal cross section up to 3.4 fb is possible

These are the only known scenarios for the 750 GeV diphoton excess without extra "ad hoc" fermions, but based on an old ($\sim$ 35 years) Susy extension of the SM

If the excess of events persists, these scenarios can be distinguished (or ruled out) experimentally:

- If $M_{A_1} \sim 211$ MeV: The A_1 decay length is macroscopic, and A_1 may decay inside the EM calorimeters
  (before the EM calorimeters, the $A_1 \to \gamma\gamma$ vertex is invisible)

- The photons can convert in the material before the EM calorimeter leading to electrons which are visible, but usually added to the photon signal in the EM (20% for rapidity $\eta \sim 0$ to 45% for $\eta \sim 1.6$)
  $\to$ photon-jets lead to more converted photons than a single photon
  $\to$ one can potentially distinguish single photons from collinear diphotons or, in the case $A_1 \to 3\pi^0 \to 6\gamma$, from collinear 6 photons (B. Dasgupta et al., arXiv:1602.04692) iff the A_1 decays occur inside the material

- If the signal originates from two nearby states H_2/H_3, their masses can potentially be separated (depending on the actual H_2/H_3 mass splitting)

Exciting times may lie ahead of us!

higgstools