A new resonance at 750 GeV?

Interpretation in the plain/phenomenological MSSM

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1. A new resonance at 750 GeV?
2. The heavier H/A states of the MSSM?
3. Charginos at the $\frac{1}{2}\mathrm{M}_{\mathbf{A}}$ threshold
4. The light stop scenario
5. Conclusion

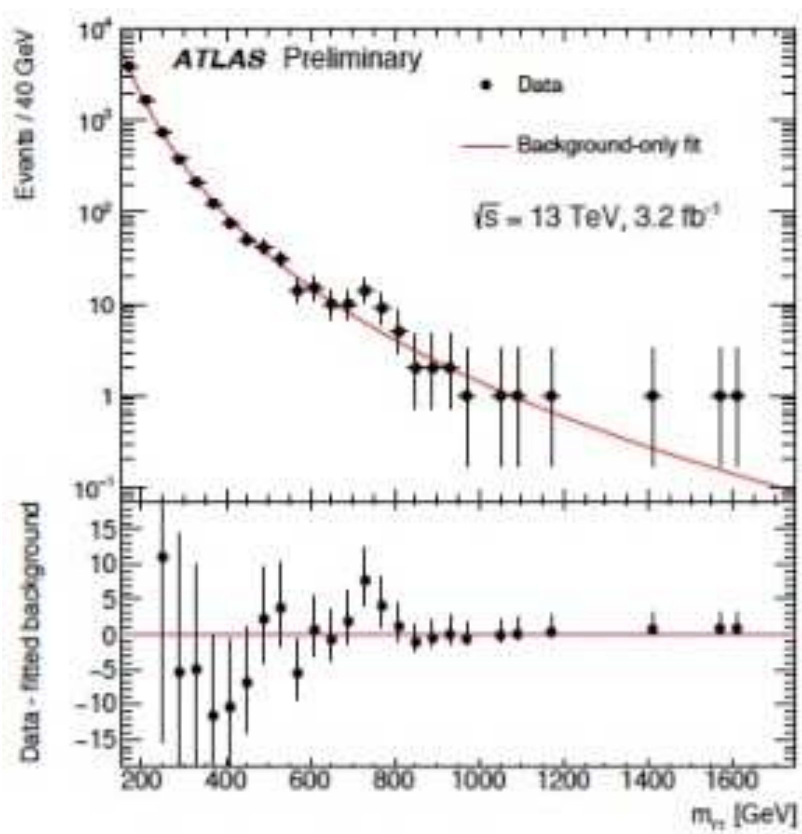
1. A new resonance at 750 GeV?

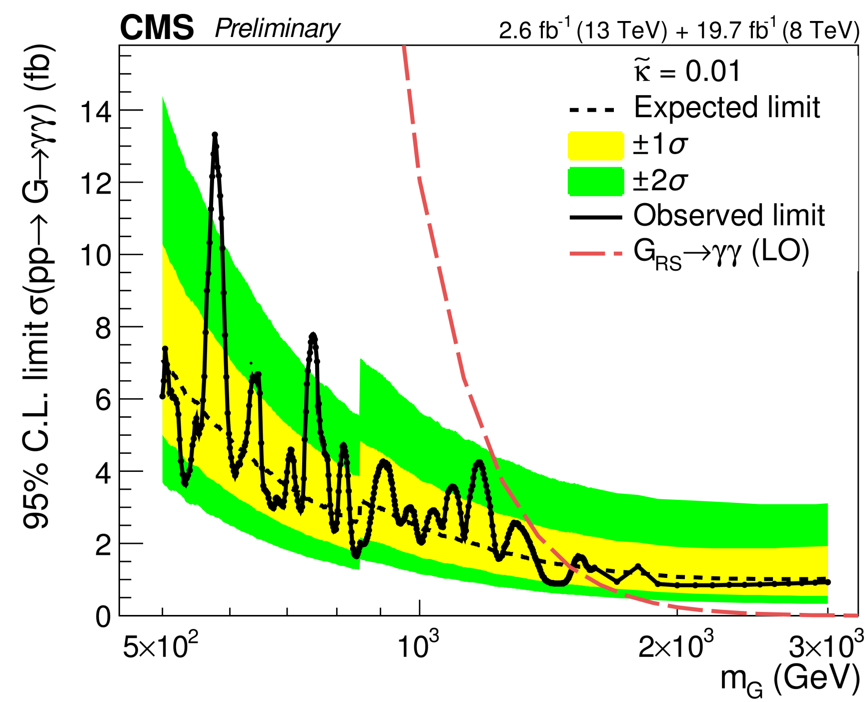
ATLAS di-photon results:

3.9σ local excess at 13 TeV
(and now about 2σ from 8 TeV).

CMS di-photon results:

3.4σ local excess at 8+13TeV
(improvement since December).





It has a smell of December 2011
the other Higgstorical day....

Two possibilities:
the biggest discovery since decades?
the mother of statistical fluctuations?

1. A new resonance at 750 GeV?

And?

Experimentalists:

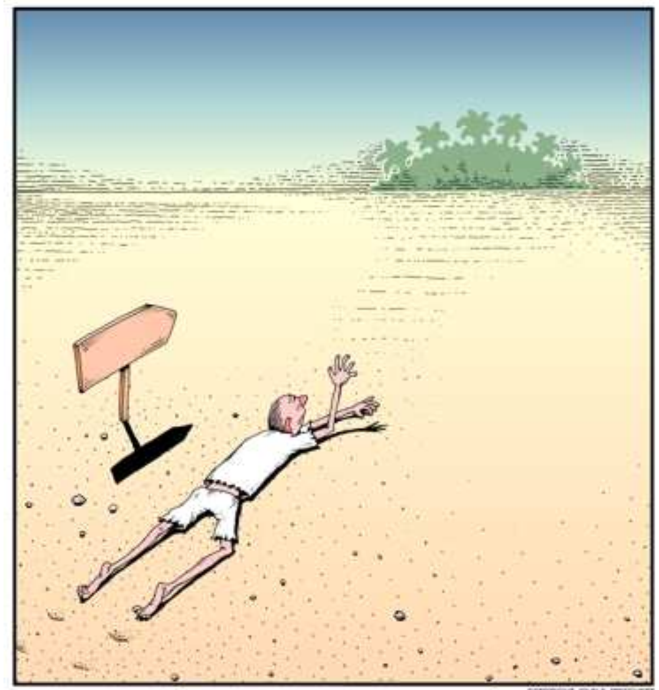
Too early to claim anything...
it is only three poor sigmas!

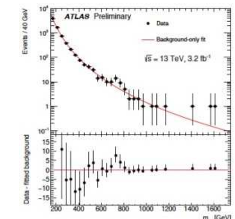
and if you insist a little bit:

So do your job and collect data
(and leave the theorists enjoy!)

Poor theorists:

Waiting for new physics for 30 years,
and recently started to get desperate...
and something interesting appears.





We do our job and interpret data!
Even more: look at far implications!

1. A new resonance at 750 GeV?

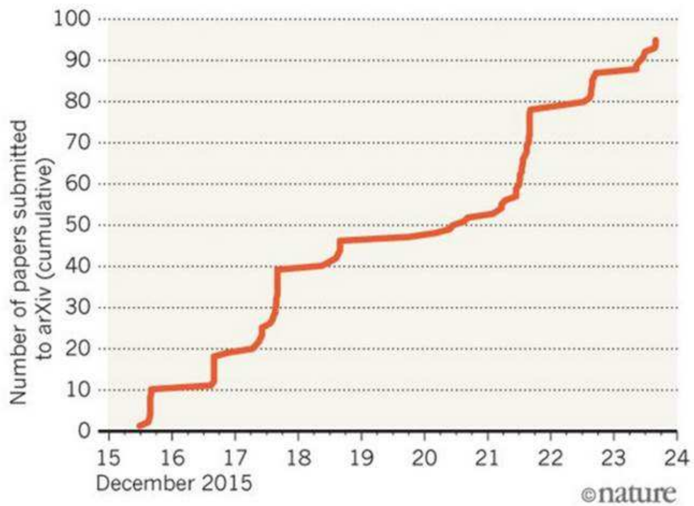
Tsunami of theory papers trying to interpret the 750 GeV diphotons:

10 papers the very first day,

100 at the end of the year,

$>$ 300 papers as of today..

Nature article/Dorigo/Jester blogs:



Florilège of explanations:

- **cascading heavy quarks,**
- **collimated 2x2 photons,**
- **new gauge bosons Z'+X**
- **sgoldstinos and other SUSY,**
- **quirks, hidden valleys?**
- **statistical fluctuation...**

But most papers are talking about a new heavy resonance:

- **Dark matter mediators**
- **Technipions/Goldstones, ..**
- **Axions,radions/dilatons,..**
- **Gravitons or any spin 2...**
- **Higgs bosons...**

and other possibilities...

I try two possible interpretations in the plain/pheno MSSM with Rp

2. The heavier H/A states of the MSSM?

In the MSSM we need two Higgs doublets: $H_1 = \begin{pmatrix} H_1^0 \\ H_1^- \end{pmatrix}$ and $H_2 = \begin{pmatrix} H_2^+ \\ H_2^0 \end{pmatrix}$.

After EWSB: 3 dof for $W_L^\pm, Z_L \Rightarrow$ 5 physical states left out: $h, H, A, H^\pm$

General 2HDM: 6+1 free parameters: $\tan\beta, \alpha, M_h, M_H, M_A, M_{H^\pm}, m_{12}$

MSSM: only two parameters at tree-level: $\tan\beta, M_A$ but radcor important:

$$M_h \lesssim M_Z |\cos 2\beta| + RC \lesssim 130 \text{ GeV} \; , \; M_H \approx M_A \approx M_{H^\pm} \lesssim M_{EWSB}$$

– Couplings of h, H to VV are suppressed; no AVV couplings (CP).

– For $\tan\beta \gg 1$: couplings to b (t) quarks enhanced (suppressed).

Φ	$g_{\Phi\bar{u}u}$	$g_{\Phi\bar{d}d}$	$g_{\Phi VV}$
h	$\frac{\cos\alpha}{\sin\beta} \to 1$	$\frac{\sin\alpha}{\cos\beta} \to 1$	$\sin(\beta-\alpha) \to 1$
H	$\frac{\sin\alpha}{\sin\beta} \to 1/\tan\beta$	$\frac{\cos\alpha}{\cos\beta} \to \tan\beta$	$\cos(\beta-\alpha) \to 0$
A	$1/\tan\beta$	$\tan\beta$	0

Decoupling limit of the MSSM: $M_A \approx M_H \approx M_{H^\pm} \gg M_Z$ and h light.

Same as alignement limit of 2HDM: $\alpha = \beta - \frac{1}{2}\pi$ so as h couplings SM-like.

1 SM-like light h and 2 CP-odd like heavy Higgses with cplg to t,b,τ only

$$\Rightarrow h \equiv H_{SM} \; , \; \Phi = H, A$$

2. The heavier H/A states of the MSSM?

Large width scenario (as in ATLAS): obtained from Φ–fermion couplings

– couplings to massive gauge bosons all eaten by the SM–like 125 GeV h,

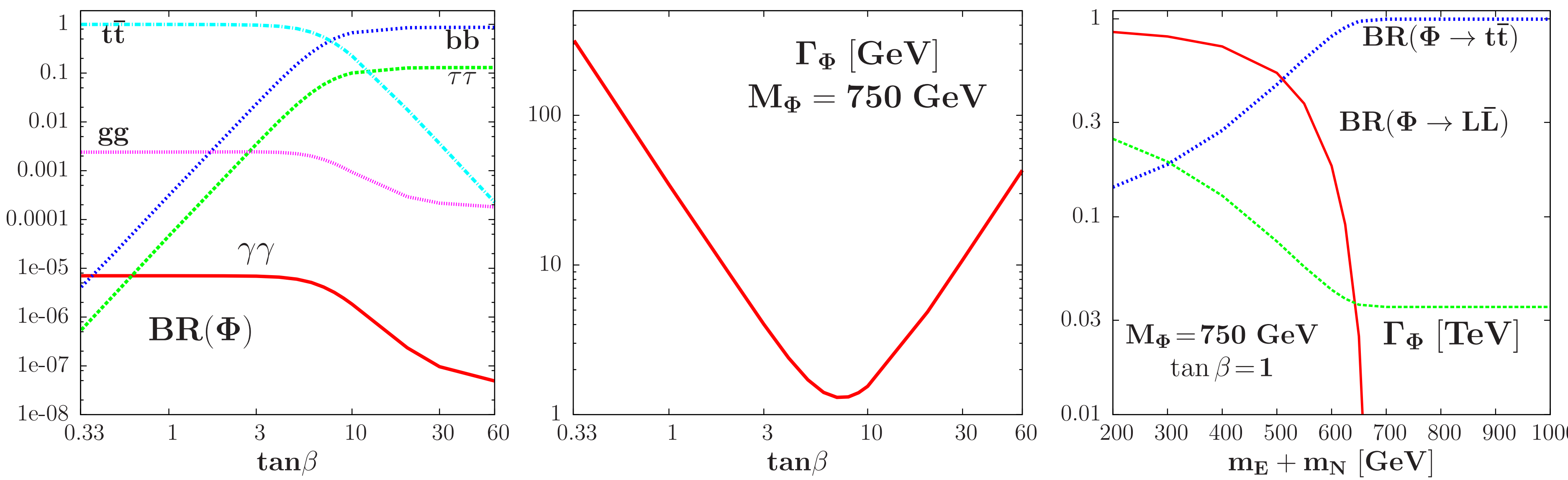
– only couplings to fermions allowed: either tops, bottoms, or new ones...

$$g_{\Phi tt} = \frac{m_t}{v}\cot\beta,\ g_{\Phi bb} = \frac{m_b}{v}\tan\beta,\ g_{\Phi\tau\tau} = \frac{m_\tau}{v}\tan\beta$$

with $\tan\beta = v_2/v_1$ small $\tan\beta \approx 1$ or large $\tan\beta \approx m_t/m_b \approx 60$

– $\tan\beta \approx 1 : BR(\Phi \to t\bar{t}) \approx 1, BR(\gamma\gamma) \approx 10^{-5},\ \Gamma_\Phi \approx 30$ GeV.

– $\tan\beta \approx 60 : BR(\Phi \to b\bar{b}) \approx 0.9, BR(\gamma\gamma) \approx 10^{-7},\ \Gamma_\Phi \approx 30$ GeV.



– $\tan\beta \approx$3–10: allow for light lepton (DM?) decays to get $\Gamma_\Phi \approx 30$ GeV.

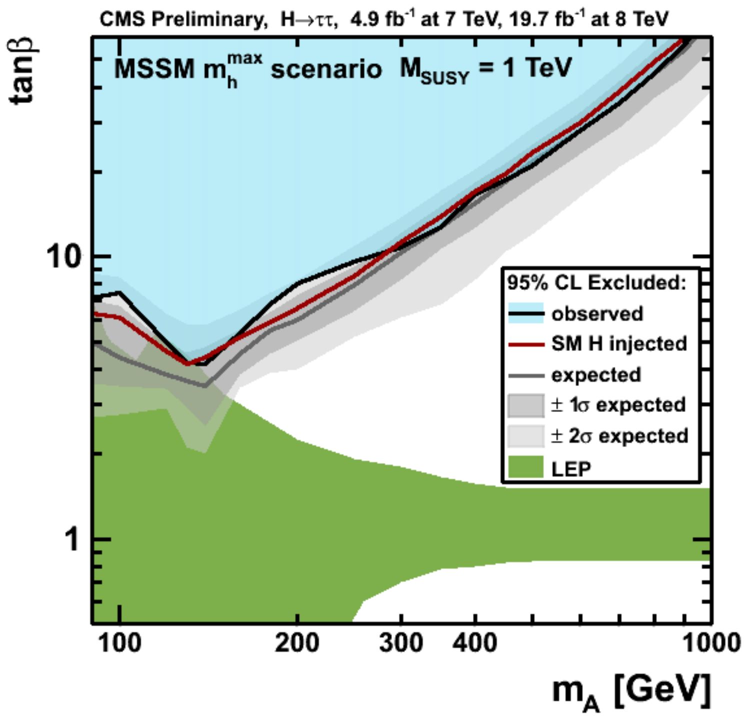
2. The heavier H/A states of the MSSM?

Not large values $\tan\beta \gtrsim 20$:

$\sigma(gg, b\bar{b} \to \Phi \to \tau\tau)$ **too large**

ATLAS and CMS very sensitive

$\Rightarrow$ **region totally excluded.**



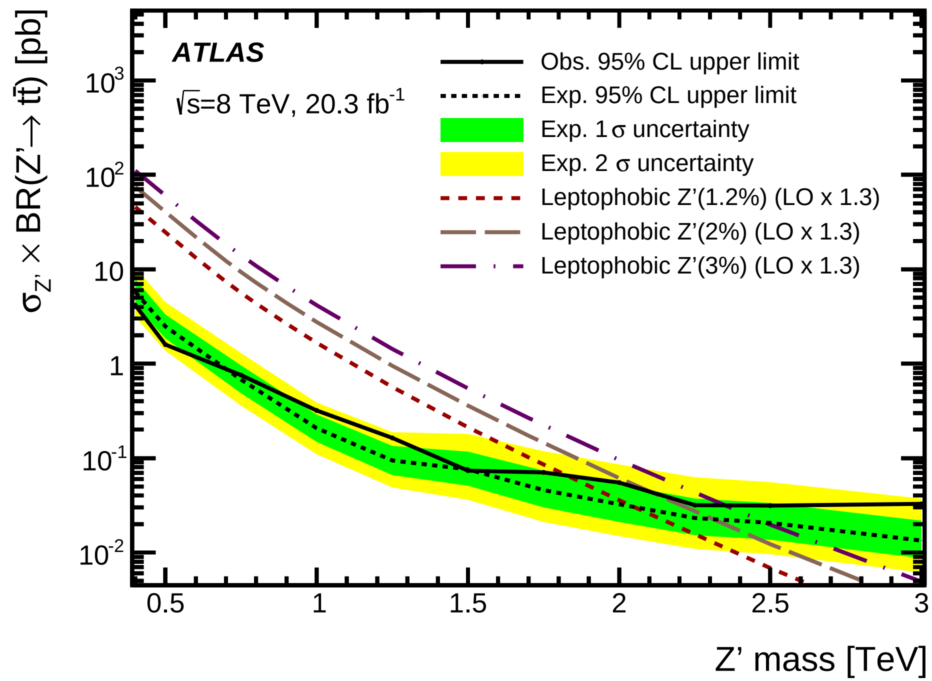
Valid only if no SUSY decays so that BR(H/A$\to\tau\tau$) maximal OK in the MSSM with large M_S.

Also not low values $\tan\beta \lesssim 1$:

$\sigma(gg \to \Phi \to t\bar{t})$ **too large**

ATLAS+CMS searches sensitive

$\Rightarrow$ **region being excluded.**



analysis valid only for spin–1
no interference with gg$\to$tt bkg
(full Φ analysis in progress...)

2. The heavier H/A states of the MSSM?

In principle and unfortunately the MSSM without new particle does not make it!

Rates for $gg \to \Phi \to \gamma\gamma$ at the LHC:

$\sigma(gg \to H) = 0.85$ **fb @13 TeV**

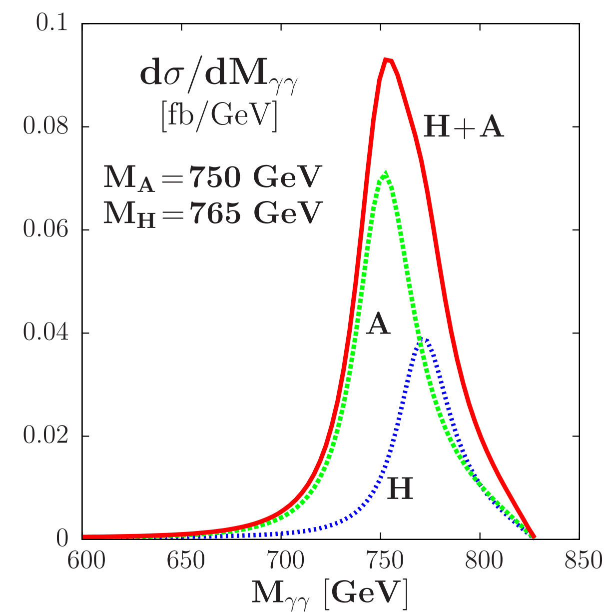
$BR(H \to \gamma\gamma) \approx 6 \times 10^{-6}$

$\sigma(gg \to A) = 1.70$ **fb @13 TeV**

$BR(A \to \gamma\gamma) \approx 7 \times 10^{-6}$

$\sigma \times BR(H + A) \approx 10^{-2}$ **fb**

We are short by at least factor 200...



Solution proposed in many instances:

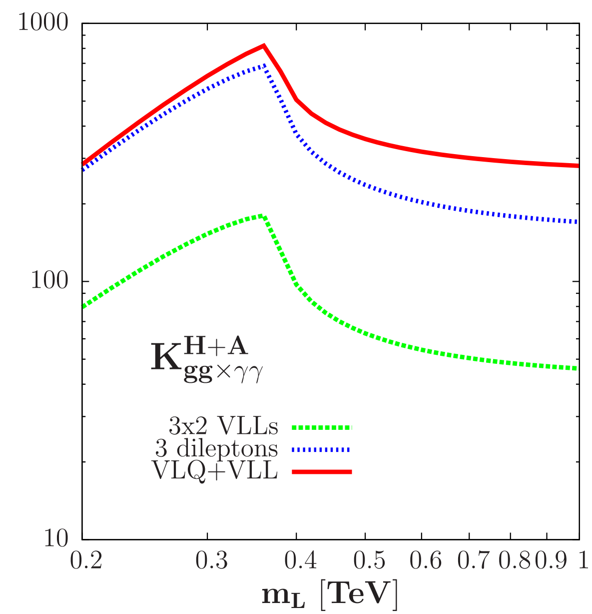
Include a bunch of VL quarks/leptons

with large Yukawa/charge/multiplicity

But watch out:

– perturbativity, EW data, LHC data

– and above all, for the light Higgs!



Angelescu+Moreau+AD:1512.04921

Ellis+ Godbole+Quevillon+AD:1601.03696

3. Charginos at the $\frac{1}{2}M_A$ threshold

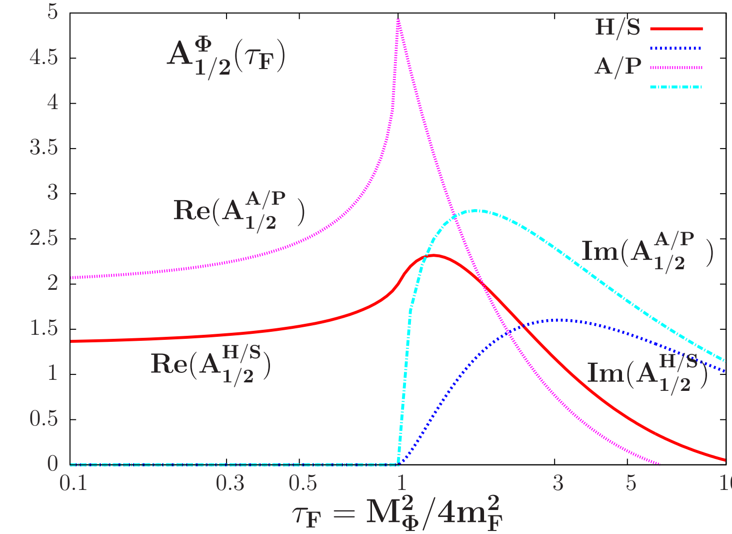
Maybe $\chi^\pm$ threshold enhancement of the $A \to \gamma\gamma$ decay rate?

Bharucha+Goudelis+AD: arXiv:1603.04464
Threshold enhancement of $\gamma\gamma$ resonances

$A^\Phi_{1/2}$ form factor for Φ=H/A$\to \gamma\gamma$

– larger for fermions than scalars
– much larger for A than for H
– maximal at the $2m_f$ threshold

$$\mathrm{Re} = \pi^2/2,\ \mathrm{Im} = 8\pi^2/m_f^2$$

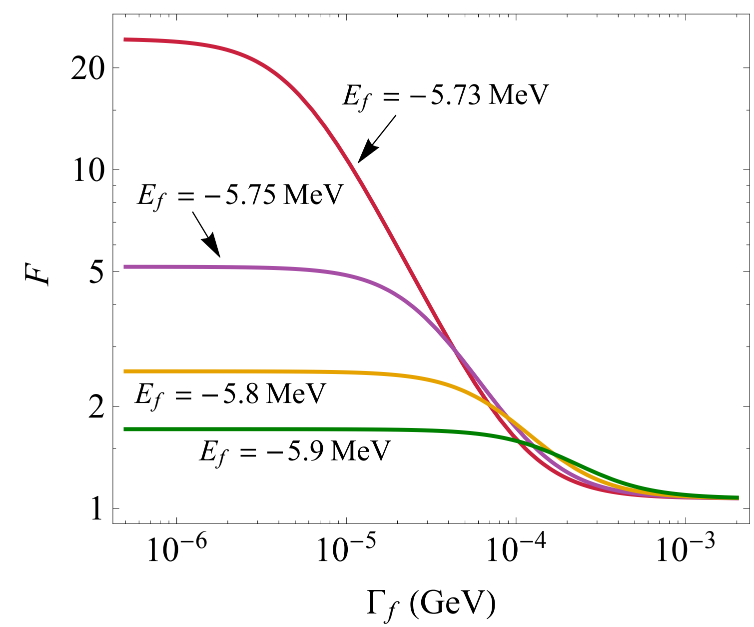


Threshold enhancement of $A^A_{1/2}$:

sit exactly ($\approx$ MeV) at threshold
$\Rightarrow$ Coulomb singularity at NLO
Regulated by fermion total width
If fermion width Γ_f very small:
very large enhancement factor

$$F = A^{1/2}_{NLO}/A^{1/2}_{LO} \gg 1$$

Very contrived but plausible??

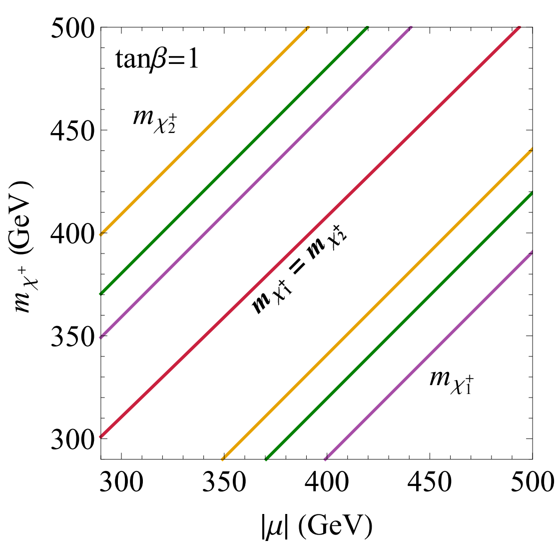


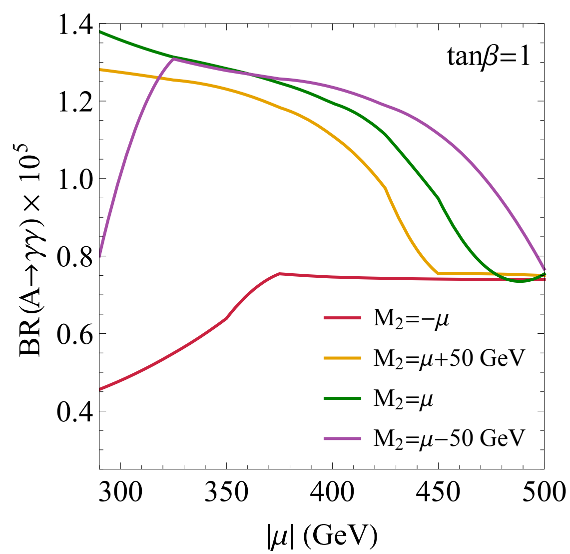
3. Charginos at the $\frac{1}{2}\mathrm{M_A}$ threshold

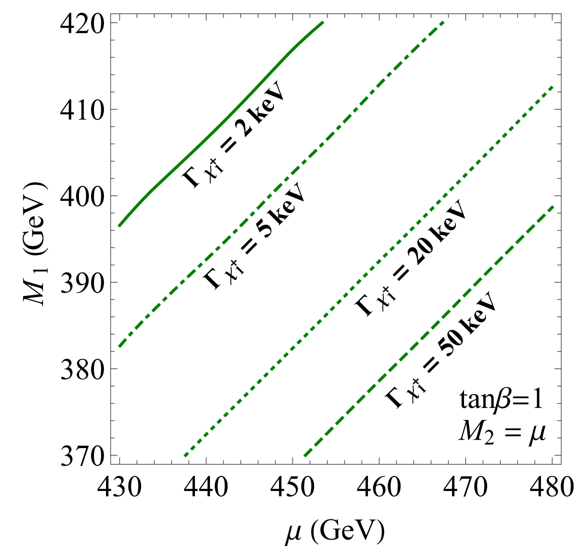
$\chi^\pm$ system described by $\mu, \mathrm{M_2}, \tan\beta$
If $\mu \approx \mathrm{M_2} \gg \mathrm{M_W}$
$\mathrm{m}_{\chi^\pm_{1/2}} \approx \mu \pm \mathrm{M_W}$
both $\chi^\pm$ enter $\mathrm{A}\gamma\gamma$

A couplings to $\chi^\pm$ only to mixtures of higgsinos–gauginos
$\mathrm{g}_{\mathrm{A}\chi_1^-\chi_1^+} \simeq -\mathrm{g}_{\mathrm{A}\chi_2^-\chi_2^+}$
total contribution tiny

Including χ_i^0 system
+ 1 input $\mathrm{M_1} \approx \mathrm{m}_{\chi_1^0}$
Only possible decay
$\chi_1^\pm \to \chi_1^0 \mathrm{W}^* \to \chi_1^0 \mathrm{f\bar{f}}$
3-body $\Rightarrow$ small $\Gamma_{\chi_1^\pm}$







Comparable param. $\mu \approx \mathrm{M_2} \approx \mathrm{M_1} \Rightarrow$ compressed spectrum $\mathrm{m}_{\chi_i^\pm} \approx \mathrm{m}_{\chi_i^0}$

- Dilepton and trilepton searches: $\mathrm{pp} \to \chi_i \chi_j \to \mathrm{n}\ell + \mathrm{E_t^{mis}}$
- Additional channels from $\tilde{\mathrm{g}} \to \chi \mathrm{jj}$ and $\tilde{\mathrm{q}} \to \mathrm{q}\chi$ if not heavy...
- $\mathrm{E_t^{mis}}$ searches (soft ℓ) including from H/A decays: DM-like searches

4. The light stop scenario

In fact one can also explain the diphoton excess (after some delay..) in terms of light stop loops that contribute to both $gg \to H$ and $H \to \gamma\gamma$!

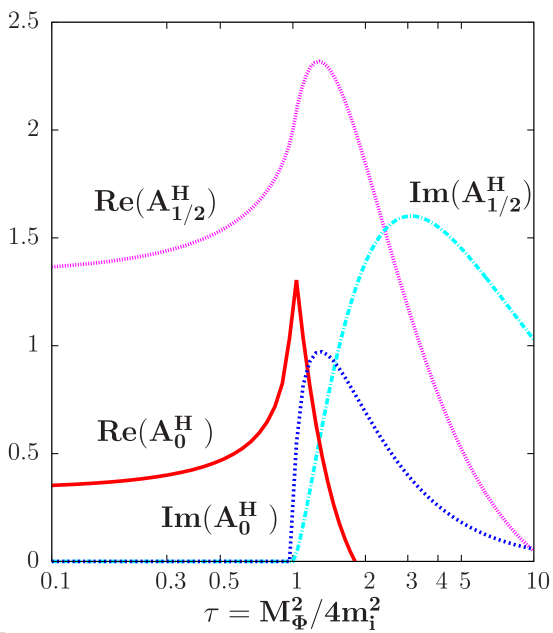
AD+Pilaftsis: arXiv:1605.01040, The 750 GeV Diphoton Resonance in the MSSM

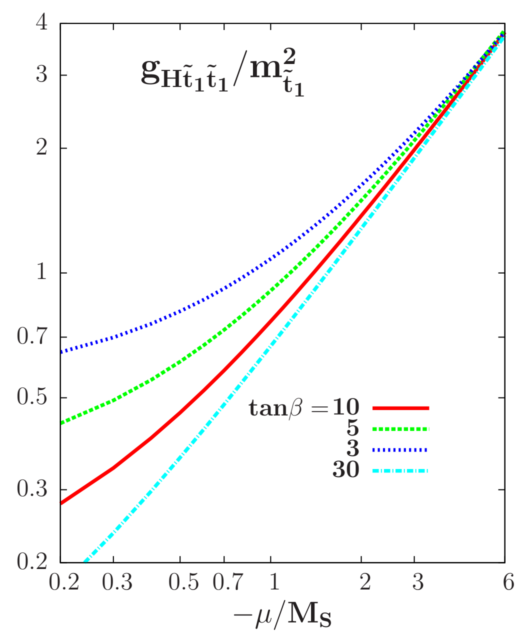
Ingredients: stop at $\frac{1}{2}M_H$ threshold, large couplings and small H width

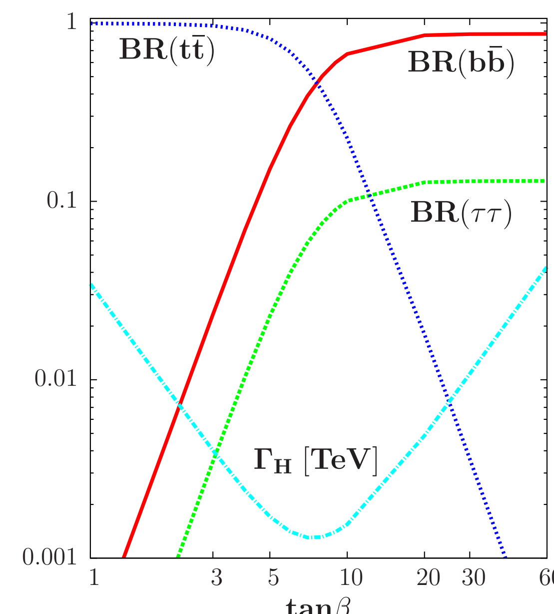
$H\gamma\gamma, Hgg$ factor A_0^H :
– small for $m_0 \gg M_H$
– $A_0^H = \frac{4}{3}$@threshold
– QED/QCD enhanced!

H couplings to stops:
$\propto \frac{1}{2} m_t (A_t \cot\beta - \mu)$
large for μ a few $\times M_S$
$(A_t - \frac{\mu}{\tan\beta} = \sqrt{6} M_S)$

$\Gamma_H \approx$ 2GeV@tanβ=3-15
$\Gamma_H \approx$ 30GeV@tanβ=1
increase of BR(H$\to\gamma\gamma$)
evade tt/$\tau\tau$ constraints

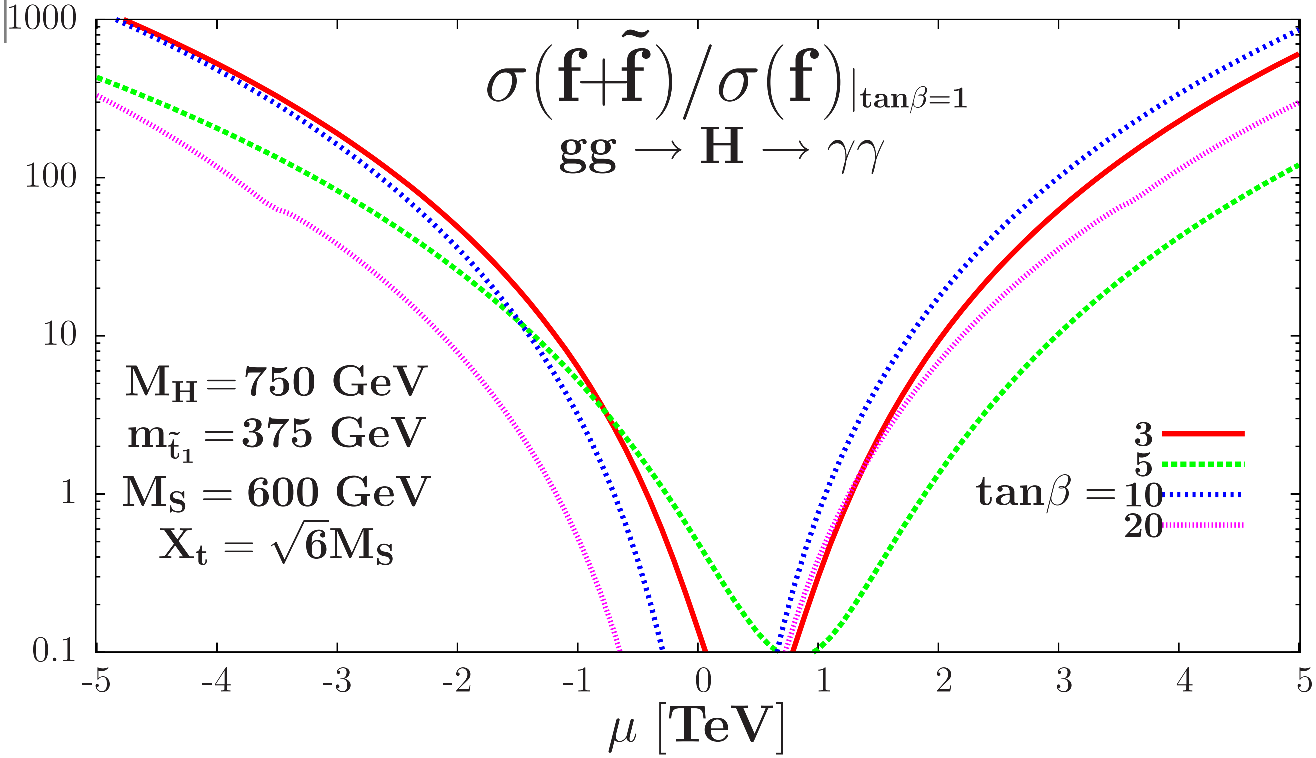


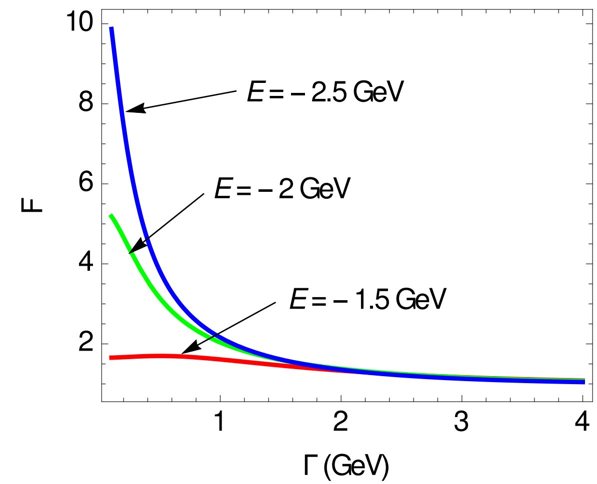




4. The light stop scenario

with all ingredients in a naive LO calculus, one gets an enhancement:



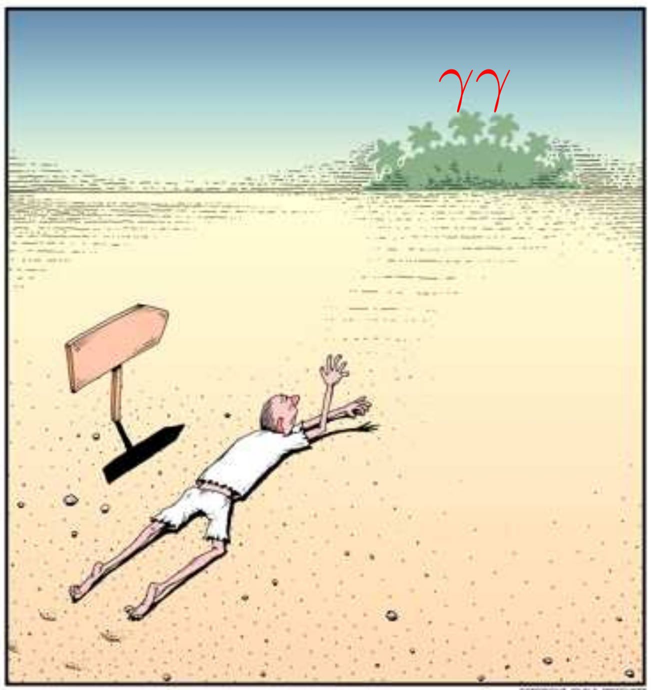


- easy factor of 100 enhancement for not so large $\mu \gtrsim$ 3TeV at $\tan\beta \approx$10.
- another factor of 2–10 enhancement at amplitude level from Coulomb!
- another enhancement by a factor 1.5–2 from mixing with stoponium...
- Natural SUSY scenario not excluded by data if $m_{\chi_1^0} \gtrsim$ 300 GeV (DM!!)
- Satisfies all constraints including that on light h mass and properties
- Interesting phenomenology to be soon probed at the LHC (eg: Z+E_T^{mis})..

5. Conclusion

And? Too early to conclude... but life suddenly became bright...

It is really a new resonance?
or simply another (big) mirage?



If true then the future is bright!
a new continent is ahead and
needs decades of exploration...

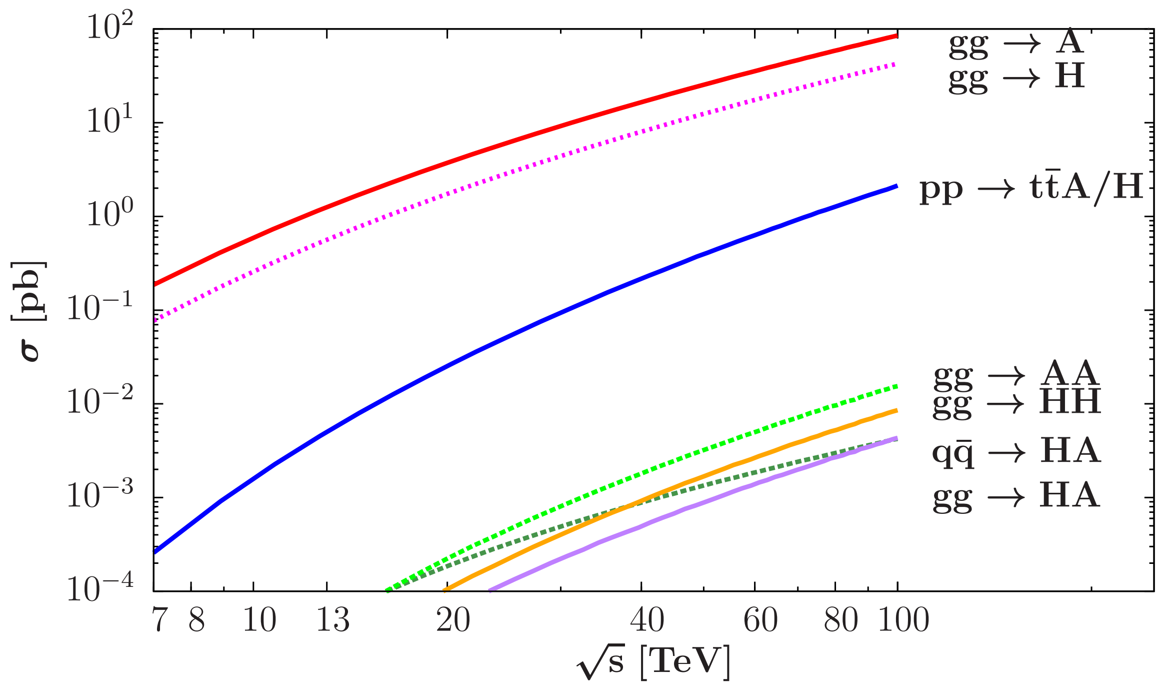
But again we should hear the experimentalists and their credo:

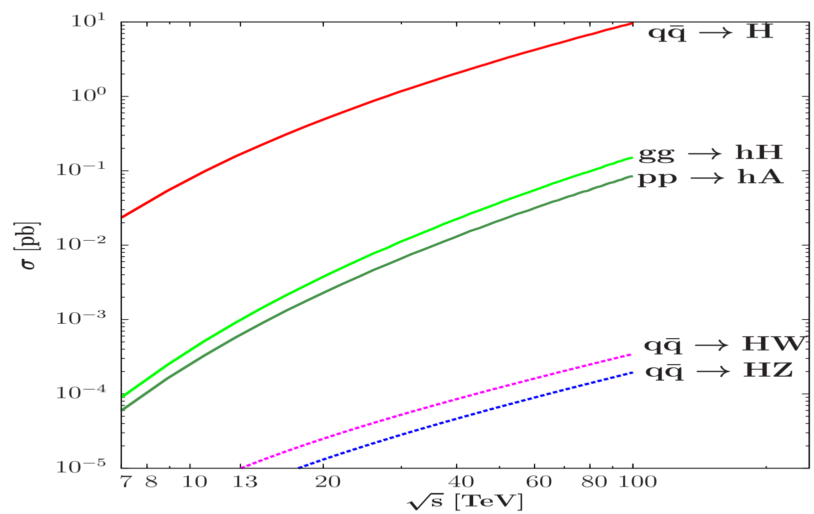
OK, OK, we wait for more data;
in summer we will know more...

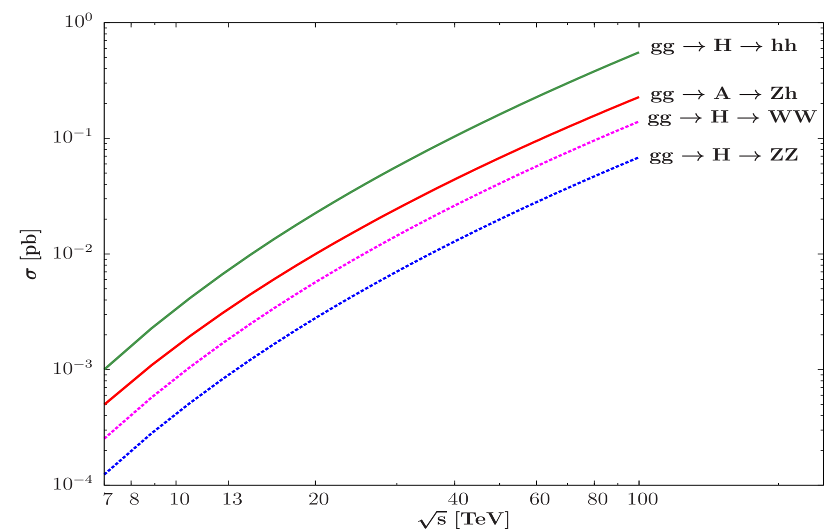
(in the meantime, let us "speculate"
and get prepared for H750GeV-GDR)

5. Conclusion

Many things to check! Just for the Higgs sector at LHC and beyond:







5. Conclusion

Many things to check! Just for the Higgs sector at $e^+e^-/\gamma\gamma$ machines: