On the sgoldstino interpretation of the diphoton excess

Joan Elias Miró, SISSA, Trieste

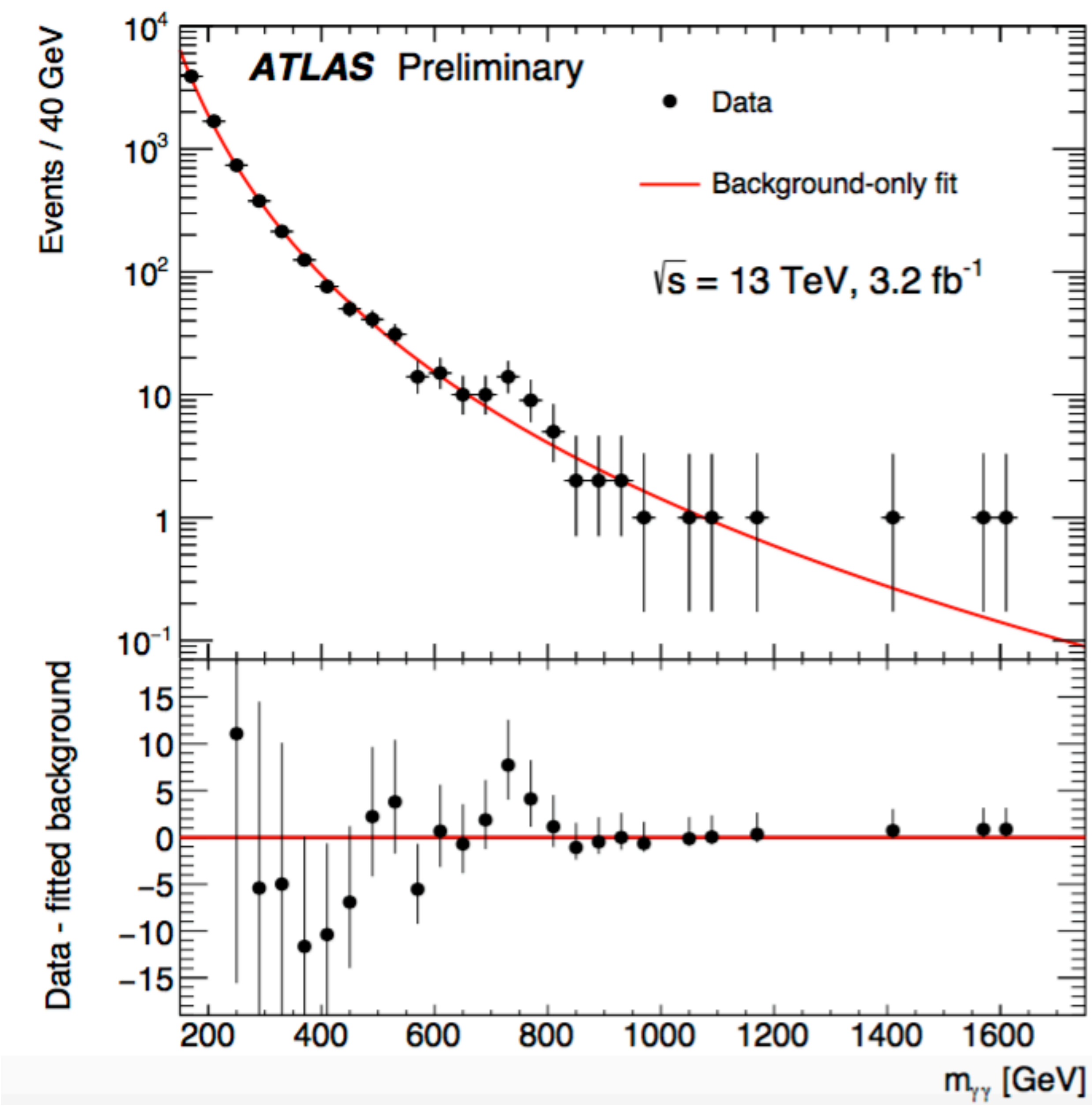
Genoa, May 2016

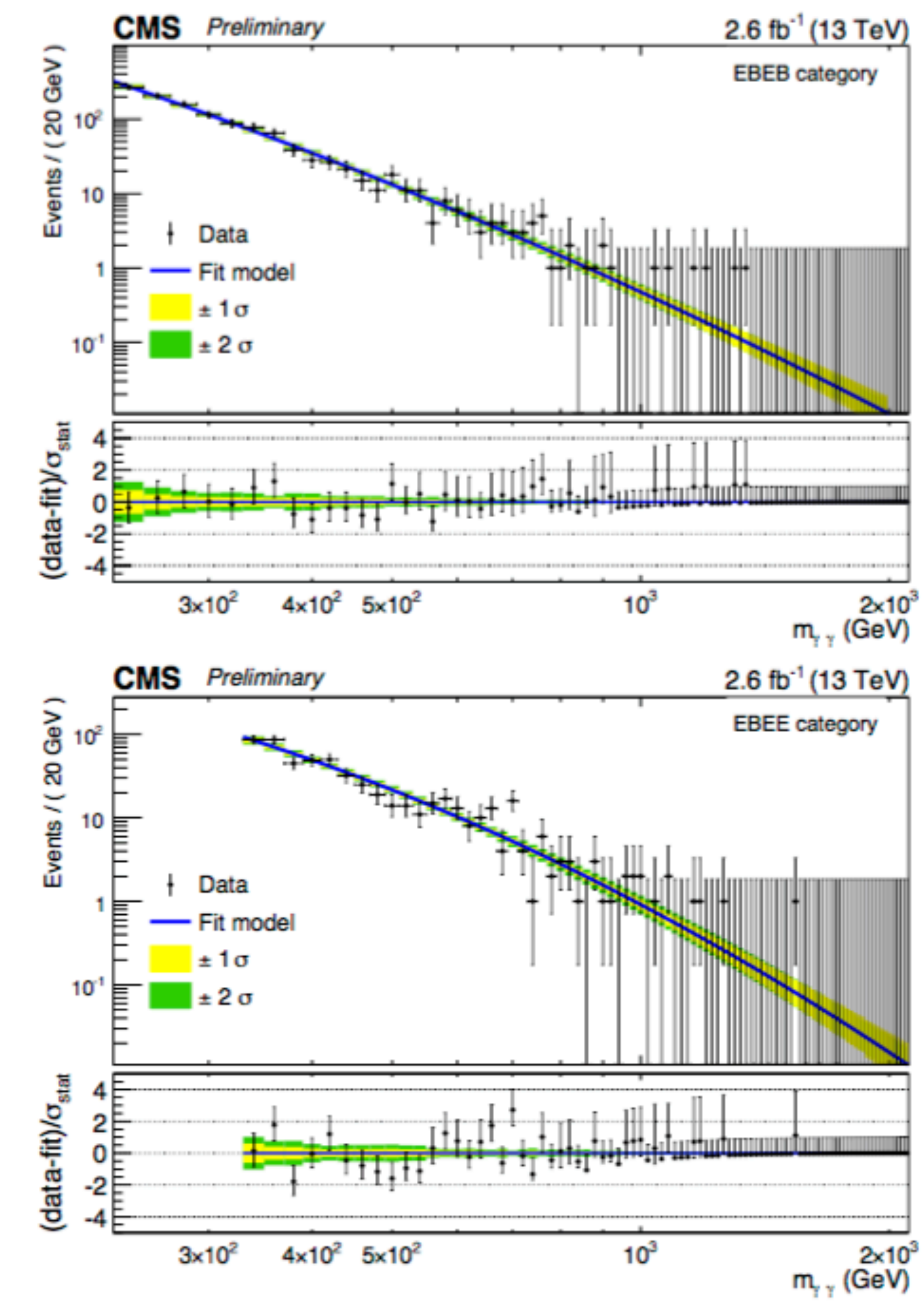
Based on **1603.05682**

w/ Baratella, JEM, Penedo, Romanino

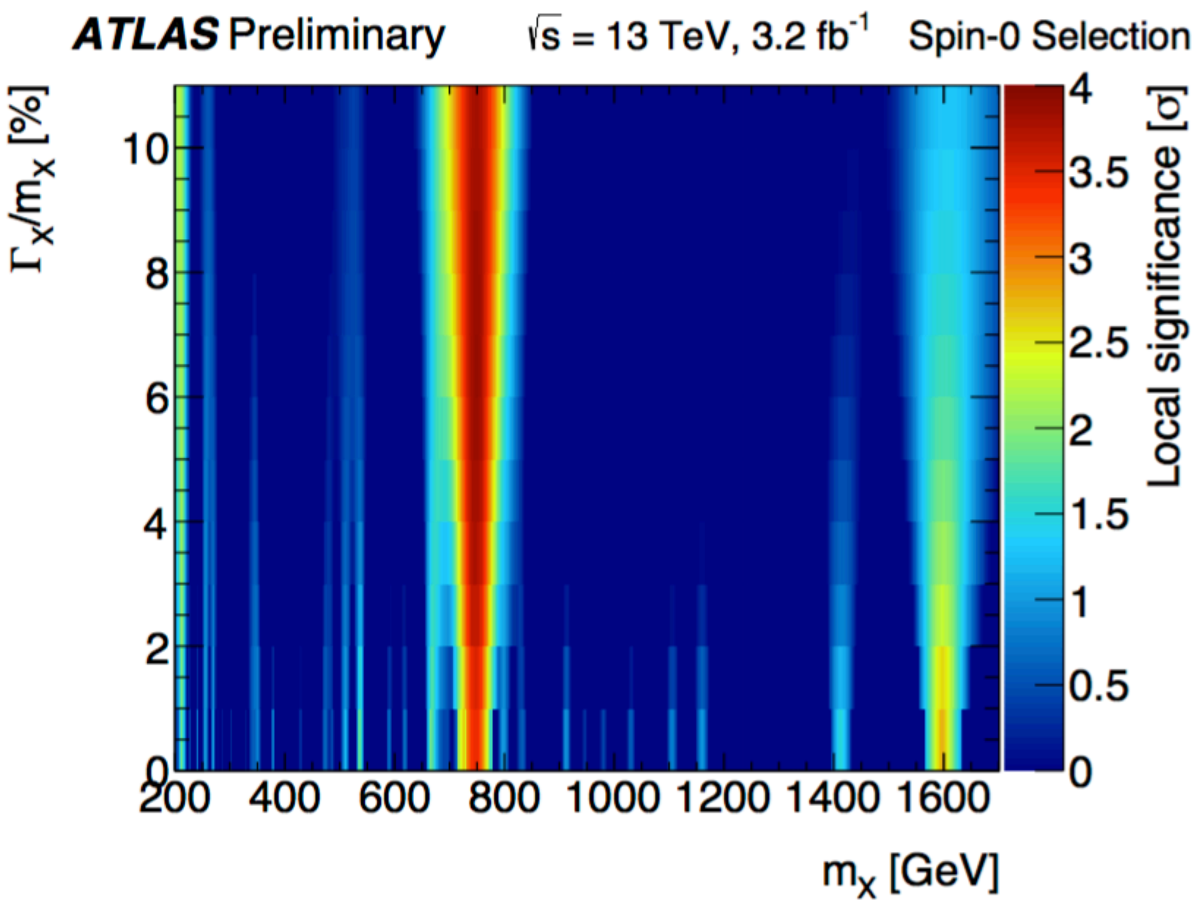
Experimental data

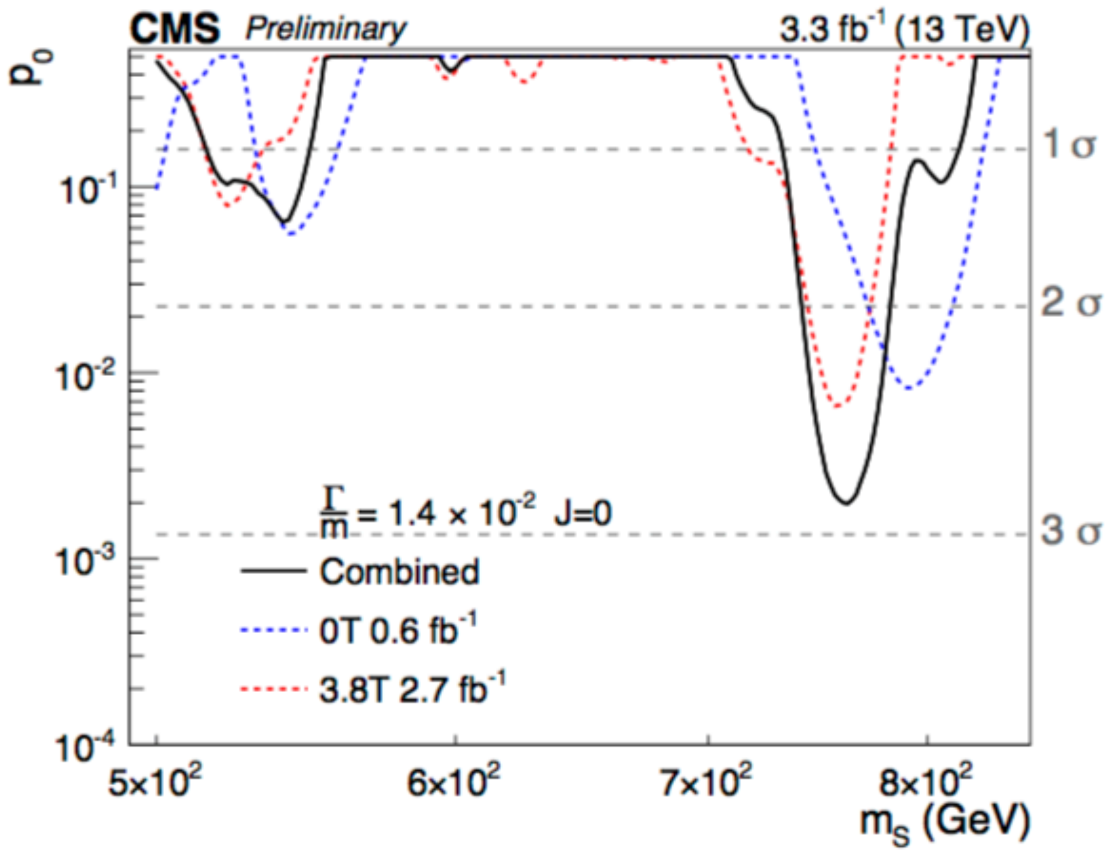
Déjà vu? excess in di-photon invariant mass hinted by both experiments!





Data at 13 TeV

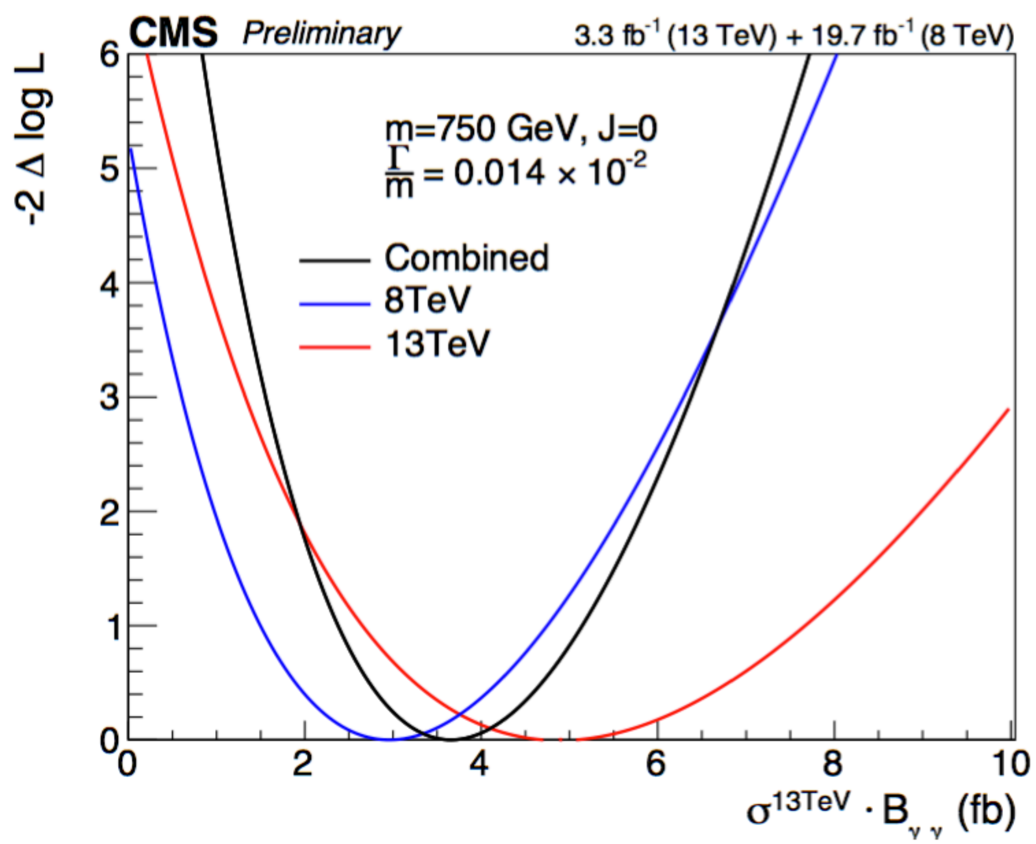




Local significance ~3σ in each experiment

X-sec very uncertain,

based on various analysis in the literature I will consider a reference value of $\sigma_{\gamma\gamma} \equiv \sigma(pp \to s \to \gamma\gamma) = 6 \text{ fb}$



(ATLAS slightly higher)

- The preferred broad width is statistically insignificant so I won't aim to explain it at this stage.

If the excess turns out to be there it is a great **opportunity for model building**,

i.e. no ad hoc dynamics.

Wouldn’t it be nice if the diphoton excess can be explained in the context of supersymmetry (SUSY)?

SUSY prominent features:

- gauge coupling unification,
- scalars mass insensitivity to the UV,
- unique extension of Poincaré,
- provides Dark Matter.

Any supersymmetric theory contains the interaction

$$\mathcal{L}_{\rm eff} = \frac{c_a}{\Lambda} \int d^2\theta \, X W_a^\alpha W_\alpha^a$$

that accounts for the mass of the gauginos

$$\mathcal{L}_{\rm eff} = \frac{M_a}{2F} \int d^2\theta \, X W_a^\alpha W_\alpha^a = \frac{M_a}{2} \lambda_a \lambda_a + \frac{M_a}{2\sqrt{2}F} \left(s \, v_a^{\mu\nu} v_{\mu\nu}^a - a \, v_a^{\mu\nu} \tilde{v}_{\mu\nu}^a \right) + \ldots$$

Any supersymmetric theory contains the interaction

$$\mathcal{L}_{\text{eff}} = \frac{c_a}{\Lambda} \int d^2\theta \, X W_a^\alpha W_\alpha^a$$

that accounts for the

But it also necessarily includes a coupling between the sgoldstino and the SM gauge bosons!

$$\mathcal{L}_{\text{eff}} = \frac{M_a}{2F} \int d^2\theta \, X W_a^\alpha W_\alpha^a = \frac{M_a}{2} \lambda_a \lambda_a + \frac{M_a}{2\sqrt{2}F} \left(s \, v_a^{\mu\nu} v_{\mu\nu}^a - a \, v_a^{\mu\nu} \tilde{v}_{\mu\nu}^a \right) + \ldots$$

Clarifications

- If SUSY is spontaneously broken, there exists a massless particle, the goldstino. It's mass is lifted by gravity corrections.

- The superpartner of the goldstino is the sgoldstino.

- The fermion in the superfield (or linear combination of them) whose F-term gets a vev is the goldstino.

- An EFT of the *(s)goldstino*: promote all MSSM soft terms to chiral fields whose F-terms get a vev.

Outline of the talk

1.- Can we fit the signal w/

$$\mathcal{L}_{\text{eff}} = \frac{M_a}{2F}\int d^2\theta\, X W_a^{\alpha} W_{\alpha}^{a} = \frac{M_a}{2}\lambda_a\lambda_a + \frac{M_a}{2\sqrt{2}F}\left(s\, v_a^{\mu\nu} v_{\mu\nu}^{a} - a\, v_a^{\mu\nu}\tilde{v}_{\mu\nu}^{a}\right) + \dots$$

and evade the lower experimental bounds on gauginos masses?

2.- To gain the right of calling it *sgoldstino* we should talk about the SUSY mediation & breaking dynamics. I discuss the first steps in this direction preserving the salient features of SUSY.

EFT description with higher dimensional operators

It is not easy to obtain large partial width $\Gamma(s \to \gamma\gamma) \equiv \Gamma_{\gamma\gamma}$.

The minimum sgoldstino decay into photons needed occurs when

i) Photons and partons involved in the production are the only decay channels $\Gamma_{\text{tot}} = \Gamma_{\gamma\gamma} + \Gamma_{pp}$, with Γ_{pp} dominating the width.

ii) The resonance is produced though gluon fusion.

Then, the Lagrangian

$$\mathcal{L}_{\text{eff}} = \frac{M_a}{2}\lambda_a\lambda_a + \frac{M_a}{2\sqrt{2}F}\left(s\, v_a^{\mu\nu} v^a_{\mu\nu} - a\, v_a^{\mu\nu}\tilde{v}^a_{\mu\nu}\right)$$

is constrained to

$$\sqrt{F} \lesssim 5\ \text{TeV}\left(\frac{M_\gamma}{200\ \text{GeV}}\right)^{1/2}\left(\frac{6\ \text{fb}}{\sigma_{\gamma\gamma}}\right)^{1/4}$$

Refs. doing similar EFT discussion:

1512.05333 - Petersson and Torre (emphasis on width)
1512.05330 - Bellazzini et al
1512.05723 - Demidov and Gorbunov
1512.07895 - Casas, Espinosa and Moreno (emphasis on width)

Then, the Lagrangian

$$\mathcal{L}_{\rm eff} = \frac{M_a}{2}\lambda_a\lambda_a + \frac{M_a}{2\sqrt{2}F}\left(s\, v_a^{\mu\nu} v_{\mu\nu}^a - a\, v_a^{\mu\nu}\tilde{v}_{\mu\nu}^a\right)$$

is constrained to

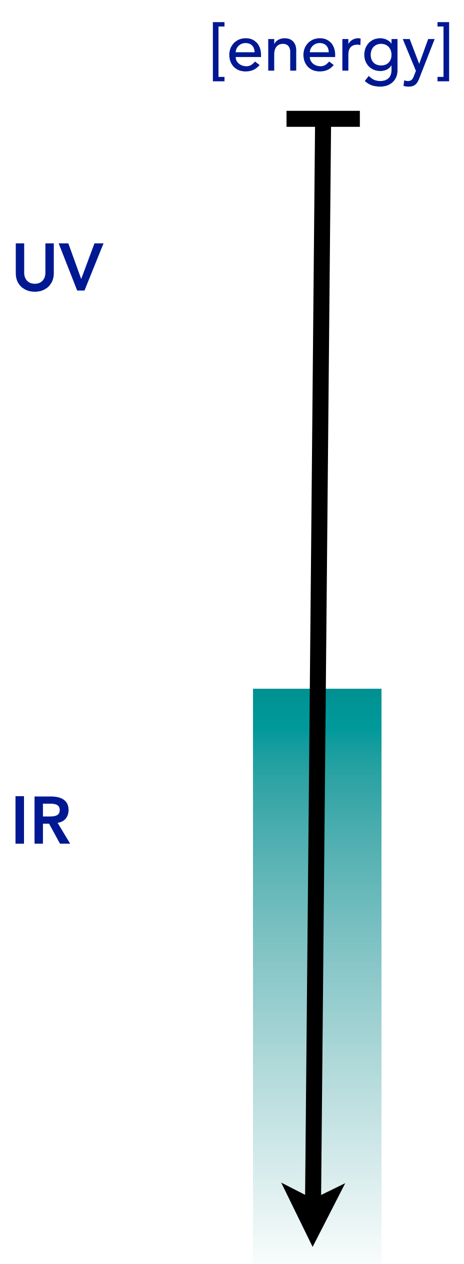
$$\sqrt{F} \lesssim 5\ \mathrm{TeV}\left(\frac{M_\gamma}{200\ \mathrm{GeV}}\right)^{1/2}\left(\frac{6\ \mathrm{fb}}{\sigma_{\gamma\gamma}}\right)^{1/4}$$

Points to a very low scale of SUSY breaking. Presumably gauge mediation is then the dominant source of gaugino mass. Not easy to get the correct gaugino masses because they are loop supressed.

Refs. doing similar EFT discussio

1512.05333 - Petersson an
1512.05330 - Bellazzini et
1512.05723 - Demidov and Gorbunov
1512.07895 - Casas, Espinosa and Moreno (emphasis on width)

A minimal UV completion: add pairs of messenger fields $\Phi_i, \bar{\Phi}_i$ in conjugate irreps of the SM. For now we assume the superfield X takes a vev $\langle X \rangle = M + F\theta^2$.



$$\mathcal{L}_\Phi = \int d\theta^2 \, \lambda_i X \Phi_i \overline{\Phi}_i + \text{h.c.}$$

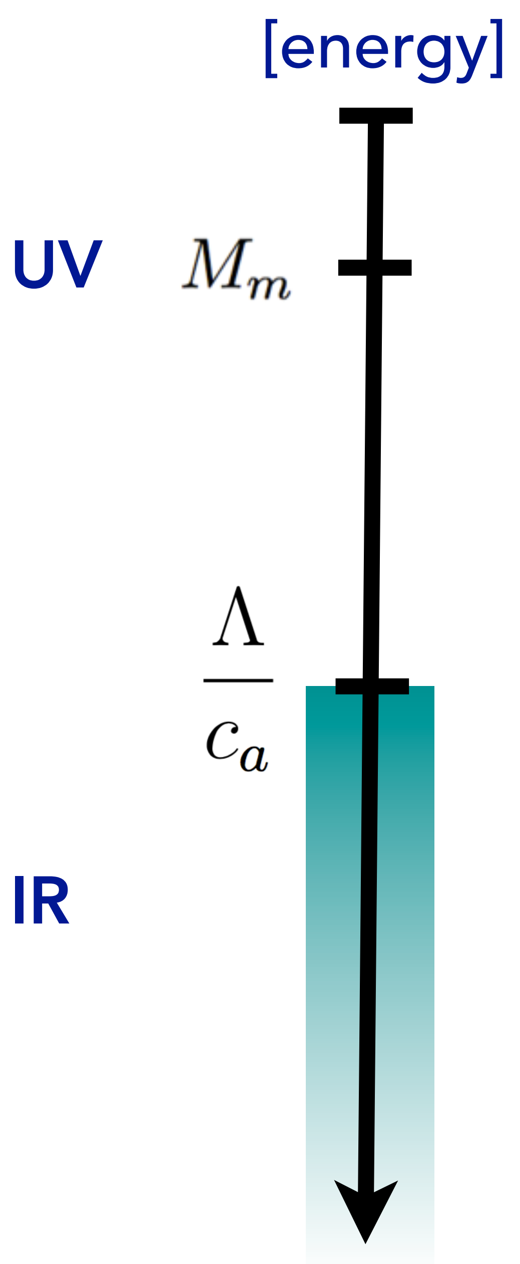
EFT description w/ MSSM + sgoldstino + ...

EFT? Two possible limits: *i*) $F \ll \lambda M^2$

ii) $F \sim \lambda M^2$

i) EFT in the F≪λM^2

We can expand the effective action in powers of F/λM^2.



$$\mathcal{L}_\Phi = \int d\theta^2\, \lambda_i X \Phi_i \overline{\Phi}_i + \text{h.c.}$$

$$\mathcal{L}_{\text{eff}} = \frac{c_a}{\Lambda} \int d^2\theta\, X W_a^\alpha W_\alpha^a \quad , \text{ with}$$

$$\frac{c_a}{\Lambda} = \frac{\alpha_a}{8\pi M} N_a\,, \text{ giving } \quad M_a = \frac{\alpha_a}{4\pi} \frac{F}{M} N_a$$

Standard well-known formula for gaugino masses, one-loop generated.

i) EFT in the $F \ll \lambda M^2$

Plug in the one-loop generated photino mass in bound found before,

$$\sqrt{F} \lesssim 5 \text{ TeV} \left(\frac{M_\gamma}{200 \text{ GeV}}\right)^{1/2} \left(\frac{6 \text{ fb}}{\sigma_{\gamma\gamma}}\right)^{1/4}$$

to obtain

$$\lambda_m N_\gamma \gtrsim 14 \frac{M_m}{\text{TeV}} \left(\frac{\sigma_{\gamma\gamma}}{6 \text{ fb}}\right)^{1/2}$$

Achievable with messengers in large SM irreps, e.g. a full family of messengers filling $\mathbf{\bar{5}} + \mathbf{10}$ of SU(5) gives $N_\gamma = 32/3$ and $\lambda > 1.5$.

i) EFT in the F≪λM^2

Plug in the one-loop generated photino mass in bound found before,

$$\sqrt{F} \lesssim 5 \text{ TeV} \left(\frac{M_\gamma}{200 \text{ GeV}}\right)^{1/2} \left(\frac{6 \text{ fb}}{\sigma_{\gamma\gamma}}\right)^{1/4}$$

to obtain

$$\lambda_m N_\gamma \gtrsim 14 \frac{M_m}{\text{TeV}} \left(\frac{\sigma_{\gamma\gamma}}{6 \text{ fb}}\right)^{1/2}$$

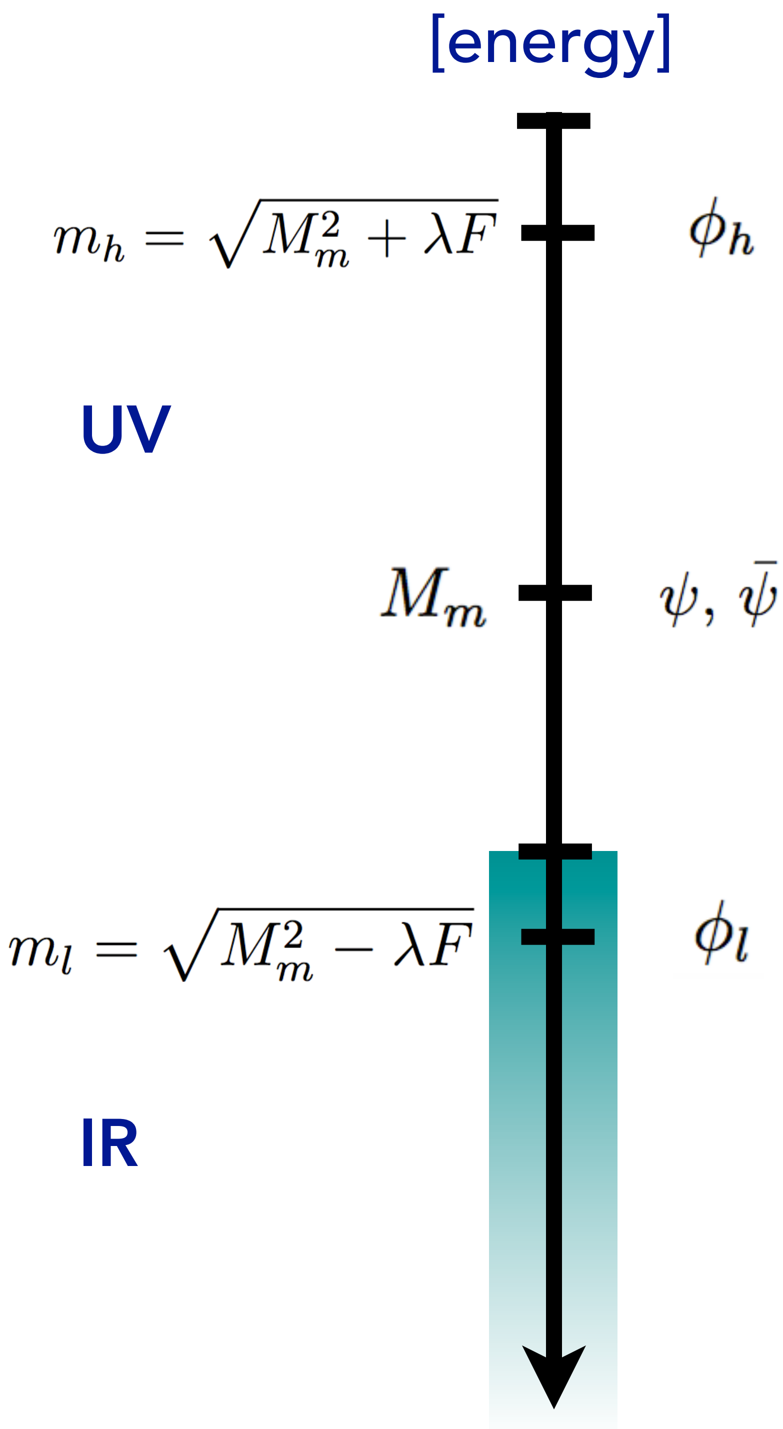
Achievable with messengers in large SM irreps, e.g. a full family of messengers filling $\mathbf{\overline{5}} + \mathbf{10}$ of **SU(5)** gives $N_\gamma = 32/3$ and $\lambda > 1.5$.

But this is at odds w/ the lower bound on the gluino mass (~1.7 TeV)

$$\lambda_m N_\gamma \gg 14 \frac{130}{N_3} \frac{M_3}{\text{TeV}} \left(\frac{\sigma_{\gamma\gamma}}{6 \text{ fb}}\right)^{1/2}$$

ii) EFT in the $F \sim \lambda M^2$

Drastic departures from the std. gauge-mediation picture.



$$\mathcal{L}_\Phi = \int d\theta^2\, \lambda_i X \Phi_i \overline{\Phi}_i + \text{h.c.}$$

$$\mathcal{L}_{eff} \neq \frac{c_a}{\Lambda} \int d^2\theta X W_a^\alpha W_\alpha^a$$

$$\mathcal{L}_{int} = \sqrt{2}\lambda^2 M s |\phi_l|^2 + \cdots$$

ii) EFT in the F~λM²

We call this scenario *near-critical regime*.

$$\mathcal{L}_{int} = \sqrt{2}\lambda^2 M s|\phi_l|^2 + \cdots \quad , \quad m_l = \sqrt{M_m^2 - \lambda F}$$

$$\Gamma(s \to \gamma\gamma) = \frac{m_s^3}{M^2}\frac{\alpha^2}{(8\pi)^3}N_\gamma^2 \longrightarrow \Gamma(s \to \gamma\gamma) = \frac{m_s^3}{m_l^2}\frac{\alpha^2}{(8\pi)^3}N_\gamma^2 \times \left(\frac{2}{3}\frac{\lambda_m M_m^2}{4m_l}\right)^2$$

ii) EFT in the F~λM^2

We call this scenario *near-critical regime*.

$$\mathcal{L}_{int} = \sqrt{2}\lambda^2 M s|\phi_l|^2 + \cdots \quad , \quad m_l = \sqrt{M_m^2 - \lambda F}$$

Enhancement of the diphoton partial width due to large trilinears

$$\Gamma(s \to \gamma\gamma) = \frac{m_s^3}{M^2}\frac{\alpha^2}{(8\pi)^3}N_\gamma^2 \quad \longrightarrow \quad \Gamma(s \to \gamma\gamma) = \frac{m_s^3}{m_l^2}\frac{\alpha^2}{(8\pi)^3}N_\gamma^2 \times \left(\frac{2}{3}\frac{\lambda_m M_m^2}{4m_l}\right)^2$$

(an O(1) fact. from the loop)

ii) EFT in the F~λM²

$$\Gamma(s \to \gamma\gamma) = \frac{m_s^3}{m_l^2} \frac{\alpha^2}{(8\pi)^3} N_\gamma^2 \times \left(\frac{2}{3} \frac{\lambda_m M_m^2}{4 m_l} \right)^2$$

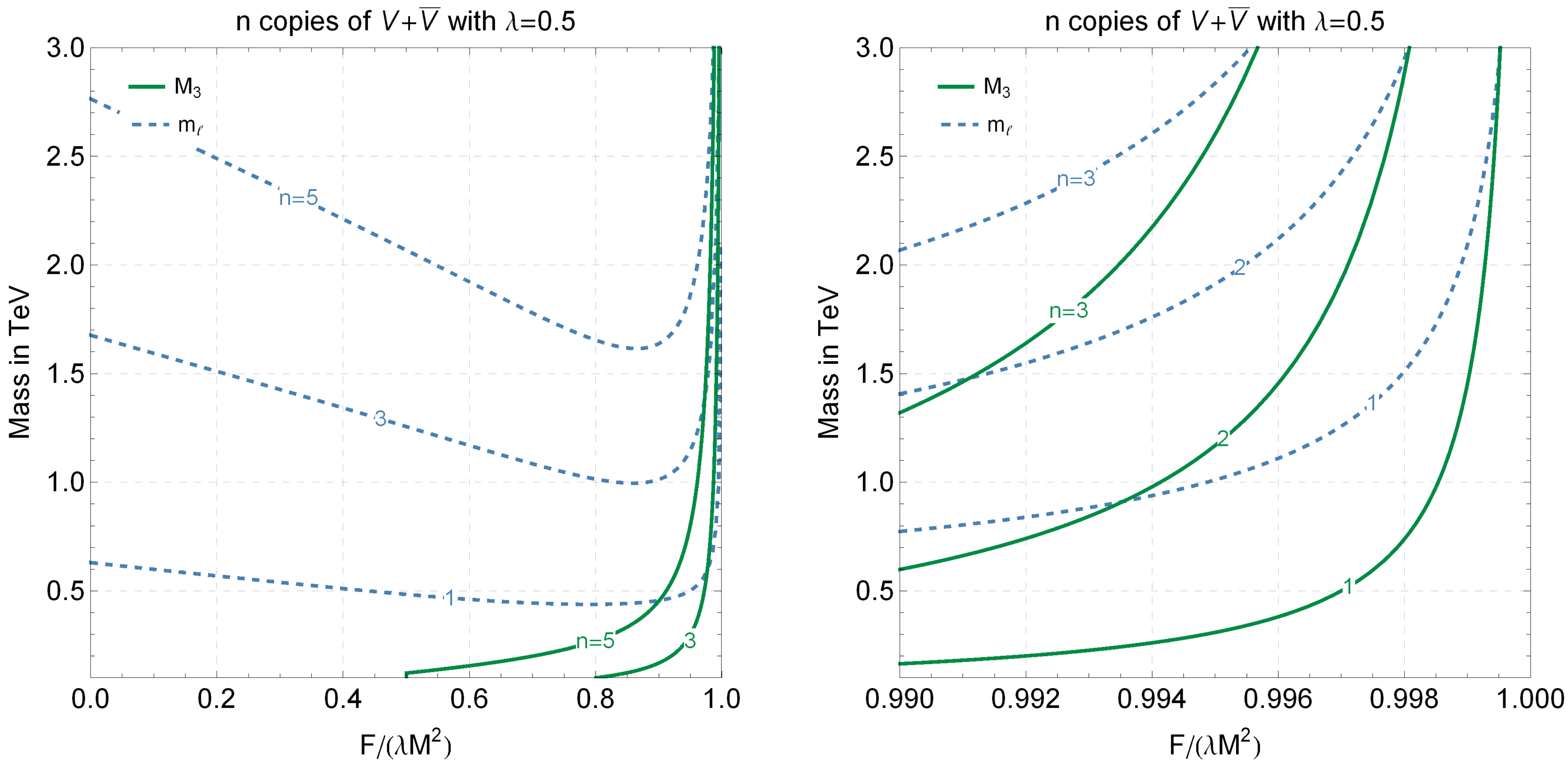
In physical processes $g_{eff}(E) \sim \frac{\lambda^2 M}{E}$

Thus, to avoid loss of perturbativity the running of the trilinear has to be "higssed"

$$g_{eff} \equiv \frac{\lambda^2 M}{m_l} = \frac{\lambda^2 M}{\sqrt{\lambda^2 M^2 - \lambda F}} \lesssim g_{eff}^* = 4\pi$$

ii) EFT in the F~λM²

Further intuition



n messenger pairs $V+\bar{V}$ with SM quantum numbers $(\mathbf{3},\mathbf{2})_{-5/6}+(\bar{\mathbf{3}},\mathbf{2})_{5/6}$

ii) EFT in the F~λM^2

Remarks

* The near-critical regime very far from being only described by MSSM +

$$\mathcal{L}_{\text{eff}} = \frac{c_a}{\Lambda} \int d^2\theta \, X W_a^\alpha W_\alpha^a$$

* **From the EFT point of view**, the near critical regime requires to tune

$$\Delta = (M_m/m_l)^2 = (g_{\text{eff}}/\lambda)^2.$$

* In the near-critical regime, for a given ***M***, gaugino masses not drastically increased (only O(1)) while decay rate decouples power-like w/ m_l.

* If multiple mess. present, in the absence of further sym, only the lightest matters because $m_i >> m_l$ due to radiative corrections.

ii) EFT in the F~λM²

Quantitative analysis

Fitting the signal requires

$$\frac{g_{eff}}{g^*_{eff}} \approx \frac{6.9}{\bar{N}_\gamma}\left(\frac{m_l}{\text{TeV}}\right)\left(\frac{\sigma_{\gamma\gamma}}{6\text{ fb}}\right)^{1/2}$$

While from the gaugino mass $M_3 = \frac{\alpha_3}{4\pi} M_m \bar{N}_3 \log 4 + \Delta M_3$ we get

$$\frac{g_{\text{eff}}}{g^*_{\text{eff}}} \approx \frac{8\lambda_{\text{m}}}{\bar{N}_3}\left(\frac{M_3 - \Delta M_3}{m_l}\right)$$

ii) EFT in the F~λM^2

Quantitative analysis

Fitting the signal requires

$$\frac{g_{eff}}{g^*_{eff}} \approx \frac{6.9}{\bar{N}_\gamma}\left(\frac{m_l}{\text{TeV}}\right)\left(\frac{\sigma_{\gamma\gamma}}{6\text{ fb}}\right)^{1/2}$$

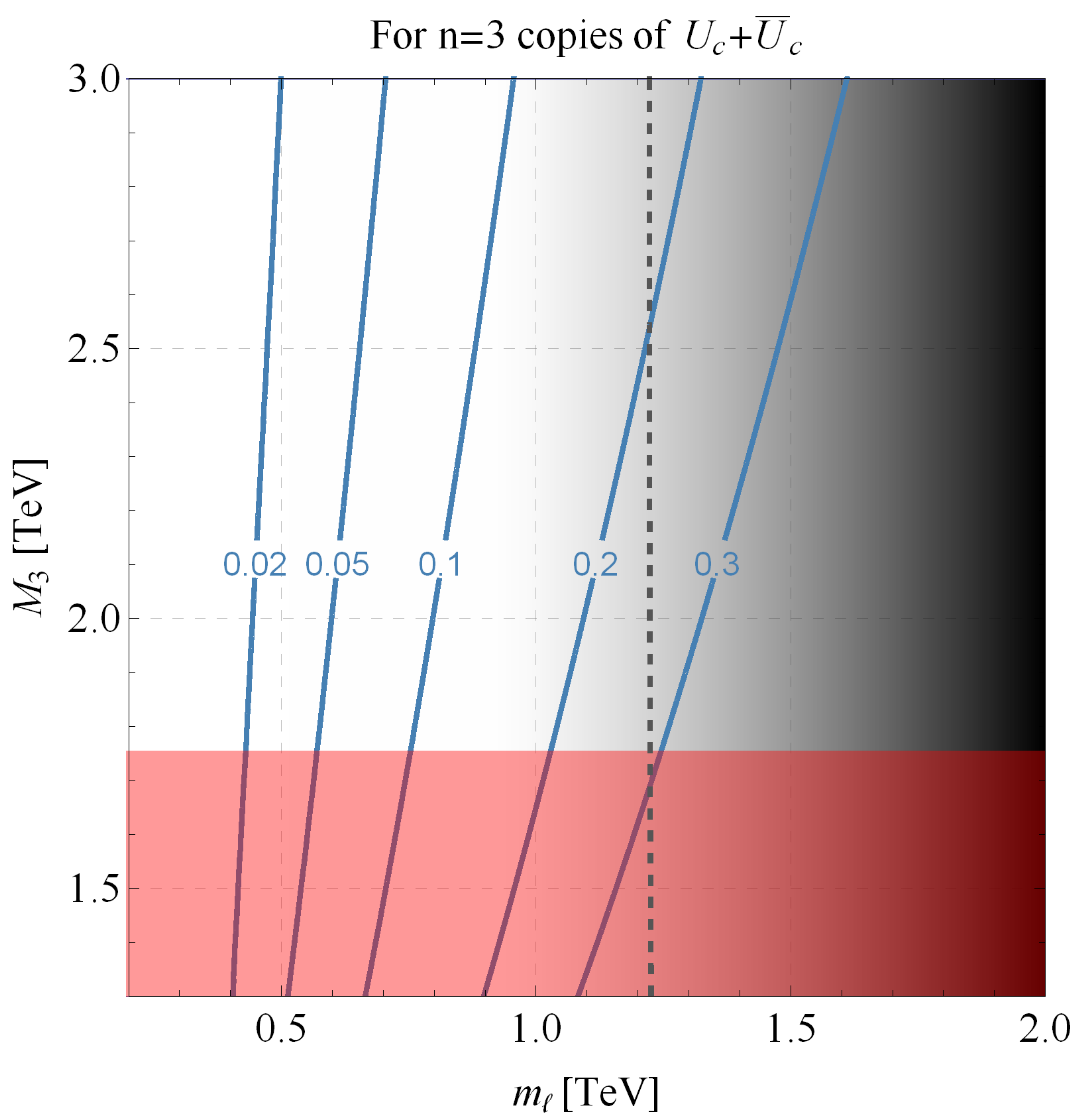
While from the gaugino mass $M_3 = \frac{\alpha_3}{4\pi} M_m \bar{N}_3 \log 4 + \Delta M_3$ we get

$$\frac{g_{\text{eff}}}{g^*_{\text{eff}}} \approx \frac{8\lambda_{\text{m}}}{\bar{N}_3}\left(\frac{M_3 - \Delta M_3}{m_l}\right)$$

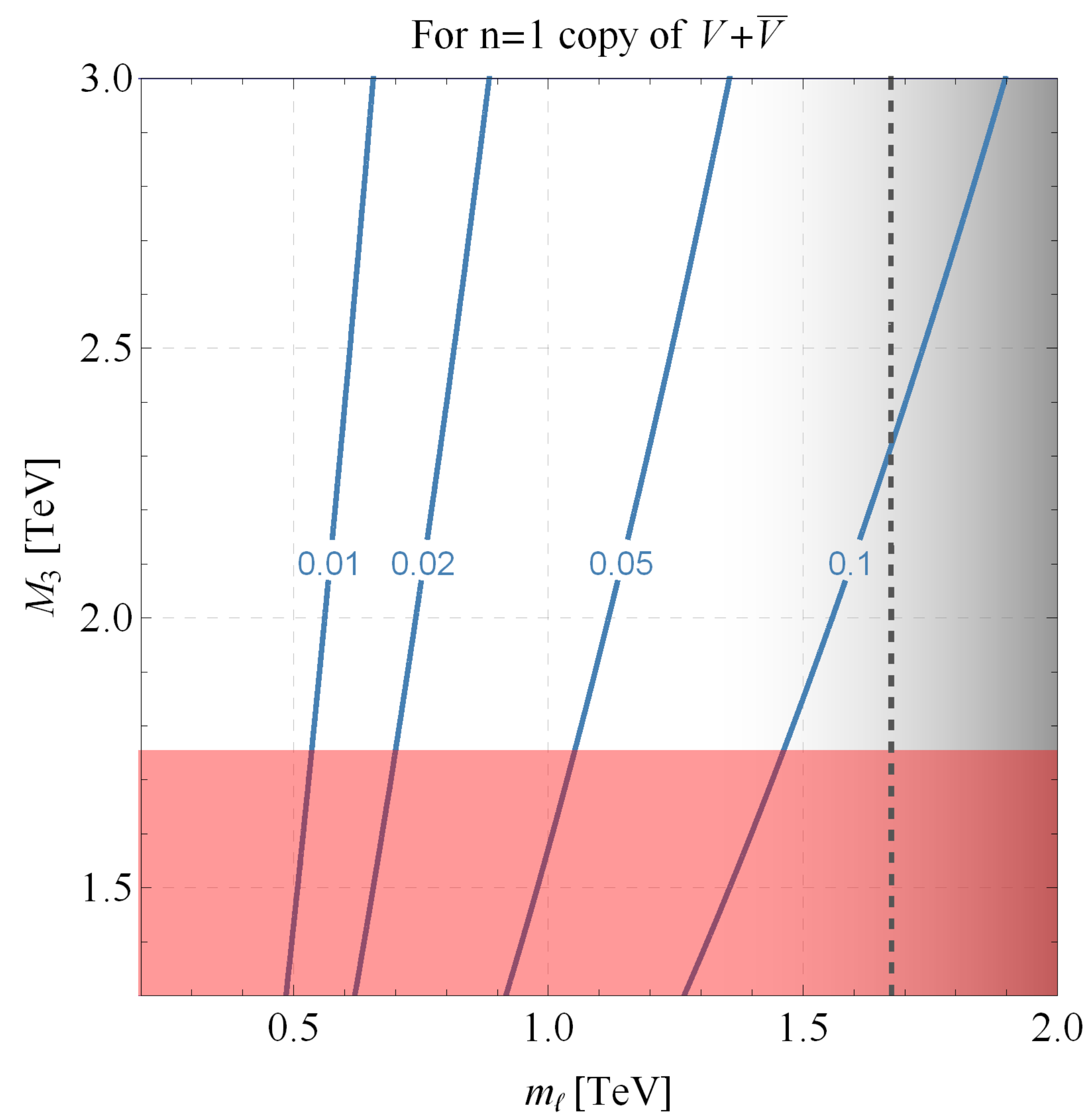
Are there SM irreps with N_γ and N_3 that satisfy the above eqs. ?

ii) EFT in the F~λM^2

<u>Quantitative analysis</u>



$N_\gamma = 8 \qquad N_3 = 3$



$(\mathbf{3},\mathbf{2})_{-5/6} + (\bar{\mathbf{3}},\mathbf{2})_{5/6}$

$(N_1, N_2, N_3) = n\,(5,3,2)$

Both examples compatible with perturbative *λ* and g_{eff}<g^*_{eff} .

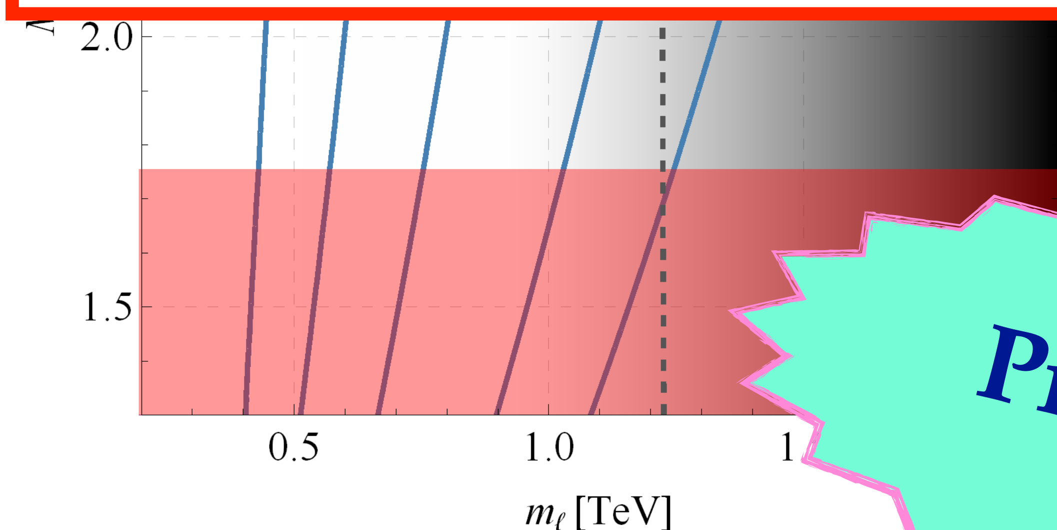
ii) EFT in the F~λM²

Quantitative analysis

For n=3 copies of $U_c + \overline{U}_c$

$$\Gamma_{Z\gamma}/\Gamma_{\gamma\gamma} \approx 0.6$$

$$\Gamma_{ZZ}/\Gamma_{\gamma\gamma} \approx 0.08$$



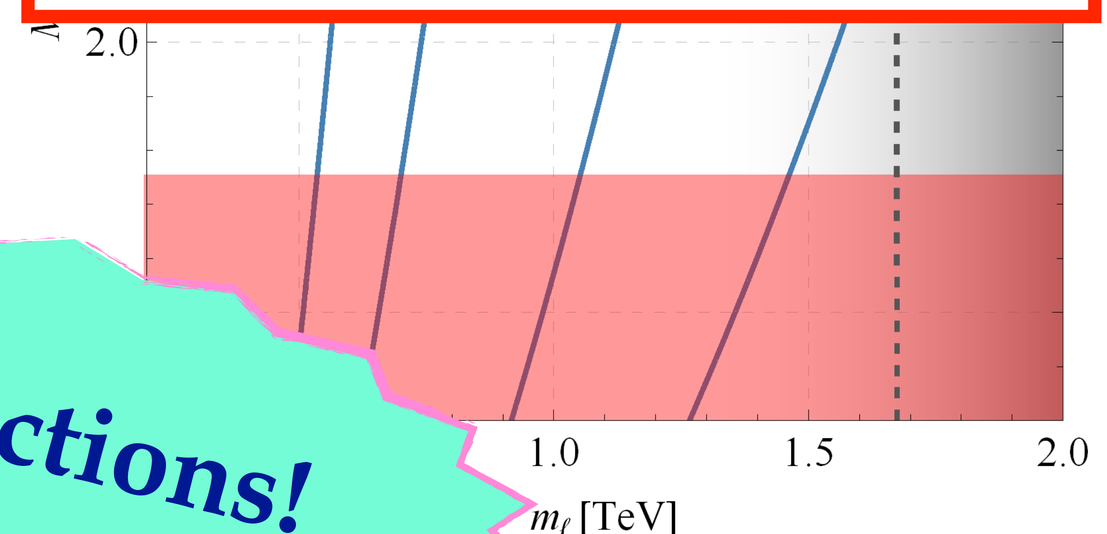
$$N_\gamma = 8 \qquad N_3 = 3$$

For n=1 copy of $V + \overline{V}$

$$\Gamma_{ZZ}/\Gamma_{\gamma\gamma} \approx 1.3$$

$$\Gamma_{Z\gamma}/\Gamma_{\gamma\gamma} \approx 0.02$$

$$\Gamma_{WW}/\Gamma_{\gamma\gamma} \approx 2.8$$



$${}_{5/6} + (\bar{\mathbf{3}}, \mathbf{2})_{5/6}$$

$$(N_1, N_2, N_3) = n\,(5, 3, 2)$$

Predictions!

Both examples compatible with perturbative λ and $g_{eff} < g^*_{eff}$.

ii) EFT in the F~λM²

Preserving unification

The first example can't be embedded into a perturbative GUT.

The second can be embedded in an adjoint of SU(5), adding adjoints of SU(3), SU(2) and a singlet.

$$(N_1, N_2, N_3) = (5, 3, 2) \longrightarrow (5, 5, 5)$$

at the border of perturbative unification.

In order to keep $(\mathbf{3}, \mathbf{2})_{-5/6} + (\bar{\mathbf{3}}, \mathbf{2})_{5/6}$ the lightest SM irrep. one has to identify ***X*** with the singlet of the adjoint.

ii) EFT in the F~λM^2

Further comments

- The near critical regime is unstable. How long lived? Do strong trilinears help on metastability?

$$\langle X \rangle = M + F\theta^2$$

- Whatever the stabilizing dynamics there are two fairly model independent decays that can't be avoided:

  * the decay to goldstinos from $m_s^2/F^2|X|^4|_D$,

  * and the decay to R-axion from SSB of R-symmetry.

Both are negligible in regions of our parameter space.

ii) EFT in the $F \sim \lambda M^2$

Further comments

- The low scale of SUSY breaking can be problematic w/ two-loop generation of SM spartners. This can be elegantly solved by doing direct GMSB with, for instance, extra ***$U(1)_X$*** symmetry.

Conclusions and outlook

- SUSY could be behind the observed excess,

- in a realization of gauge mediation not so much explored.

- We would be learning about the SUSY breaking dynamics!

- Many directions to be further inspected:

    * Refined collider analysis

    * stability of the potential which will require

    * further model building

    * ...