The R-axion:
new signs of SUSY at the LHC

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Bellazzini Mariotti Redigolo FS Serra, works in progress

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Take-home message

Any other sign of SUSY to be looked for at the LHC?

beyond gluino, stop, EWinos, MSSM scalars,…

Spontaneously broken R-symmetry is quite generic

provides a naturally light hidden sector state, the “R-axion”

This state could be the first sign of SUSY at the LHC

when superpartners are heavy! (strong coupling, split,…)

R symmetries: one slide recap

N = 1 SUSY always accompanied by a continuous $U(1)_R$ = “R-symmetry"

$$R: \ \theta \to e^{i\alpha}\,\theta \qquad [R, Q] = -Q$$

R-charge assignments: $$\Phi = \phi + \sqrt{2}\theta\,\psi + \theta^2\,F$$

$$r_\phi = r_\Phi$$
$$r_\psi = r_\Phi - 1$$
$$r_F = r_\Phi - 2$$

Vector superfields are real $\Rightarrow$ gauginos have $r_\lambda = 1$

Lagrangian $\mathcal{L}$ R-symmetric $\Rightarrow R(W) = 2$

($\Leftarrow$ if Kahler canonical)

$$\mathcal{L} \supset \int d^2\theta\,W \;+\; \text{c.c.}$$

W superpotential

Why bothering with R-symmetries?

Nelson-Seiberg "theorem": Nelson Seiberg hep-ph/9309299

i) F-term SUSY breaking in global minimum

ii) W generic
(i.e. contains all terms not forbidden by symmetries)

$\Rightarrow$ Theory has an exact $U(1)_R$

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In MSSM + closer relatives $U(1)_R$ needs to be broken because of

gaugino masses

$$\mathcal{L} \supset m_\lambda \, \lambda\lambda$$

EW symmetry breaking & Higgsino masses

$$\mathcal{L} \supset B_\mu \, H_u H_d + \text{c.c.} \quad \& \quad W \supset \mu \, H_u H_d$$

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Ways out?

Break $U(1)_R$ spontaneously $\Longrightarrow$ Massless goldstone in the spectrum R-axion a !

Violate i) or ii) (e.g. SUSY broken in metastable vacuum) Intriligator Seiberg Shih 2006, 2007

MRSSM: Dirac masses to gauginos + 2 Higgs-like superfields Kribs Poppitz Weiner 0712.2039

The R-axion

It is quite generic to have an explicit R-symmetry breaking $\Rightarrow m_a \neq 0$

from cosmological constant Bagger Poppitz Randall hep-ph/9405345

we live in a metastable SUSY-breaking vacuum

…

In this talk, R-axion mass as a ~ free parameter

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Could it be the first SUSY sign @ the LHC?

Least possible ingredients in the IR: SM a G

from $U(1)_R$ breaking

Goldstino from SUSY breaking

Free parameters

m_a

f_a $U(1)_R$ breaking scale, controls a pheno

F SUSY breaking scale, controls G pheno

The R-axion pheno Lagrangian-I

Tool: constrained superfield formalism

Komargodski Seiberg 0907.2441

$$X = \frac{G^2}{2\,F_X} + \sqrt{2}\theta\, G + \theta^2\, F_X$$

$$\mathcal{R} = e^{i\mathcal{A}/f_a} = e^{ia/f_a + O(a\,G,\dots)}$$

satisfy the constraints $\begin{cases} X^2 = 0 \\ X(R^\dagger R - 1) = 0 \end{cases}$

~ analogous to ordinary goldstones

$U^\dagger U = 1 \quad U = e^{i\pi}$

Most general effective Lagrangian:

$$\mathcal{L}_{G+a} = \int d^4\theta\,(X^\dagger X + f_a^2 \mathcal{R}^\dagger \mathcal{R}) + \int d^2\theta\,(F X + w_R \mathcal{R}^2) + \text{c.c.}$$

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First pheno prediction (valid for any UV completion!):

$$\boxed{-\frac{w_R}{f_a\,F^2}\,\Box a\,\bar{G} i\gamma_5 G}$$

R-axion decays to missing energy

$$w_R < \frac{1}{2} f_a F \longrightarrow \boxed{\Gamma_{a\to GG} < \frac{1}{16\pi}\frac{m_a^5}{F^2}}$$

Dine Festuccia Komargodski 0910.2527

see also Bellazzini 1605.06111

The R-axion pheno Lagrangian-II

$$r_X = 2 \quad r_{\mathcal{W}} = 1$$

$$\mathcal{L}_{\text{gauge}} = \int d^2\theta \left(\frac{1}{4} - ig^2 \, \frac{c^{\text{eff}}}{16\pi^2}\mathcal{A}\right)\mathcal{W}^2 \; + \int d^2\theta \, \frac{m_\lambda}{2F} X R^{-2}\mathcal{W}^2 \; + \text{ c.c.}$$

$$R_H \equiv r_{H_u} + r_{H_d}$$

$$\mathcal{L}_{\text{Higgs}} \supset \int d^4\theta \left(\frac{\mu}{F}\, X^\dagger H_u H_d \mathcal{R}^{2-R_H} - \frac{B_\mu}{F^2}\, X^\dagger X H_u H_d \mathcal{R}^{-R_H} + \text{c.c}\right)$$

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Induces mixing $\delta = R_H \frac{v}{f_a} \frac{s_{2\beta}}{2}$

between a and MSSM pseudoscalar A

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$$\boxed{-i\, a\, R_H \left(c_\beta^2 \frac{m_u}{f_a} \bar{u}\gamma_5 u + s_\beta^2 \frac{m_d}{f_a} \bar{d}\gamma_5 d + s_\beta^2 \frac{m_\ell}{f_a} \bar{\ell}\gamma_5 \ell\right)}$$

$$\boxed{\frac{\delta^2}{v} (\partial_\mu a)^2 h}$$

(Here and in the following $m_A,\, m_{\tilde{f}} \gg m_a$)

Example of a “UV" completion

Very low energy SUSY breaking

motivated by:

Naturalness + Higgs mass Gherghetta Pomarol 1107.4697

+ LHC exclusions Buckley et al. 1610.08059

Gravitino cosmology Ibe Yanagida 1608.01610

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Power counting à la SILH (give up on perturbativity)

Giudice et al. 2007 + Cohen et al. 1997, Luty 1998

$$\mathcal{L} = \frac{m_*^4}{g_*^2}\left[\int \frac{d^4\theta}{m_*^2}\,\widehat{K}\left(\frac{g_*\Phi}{m_*^{\Delta_\Phi}}, \frac{g_*\Phi^\dagger}{m_*^{\Delta_\Phi}}\right) + \int \frac{d^2\theta}{m_*}\,\widehat{W}\left(\frac{g_*\Phi}{m_*^{\Delta_\Phi}}\right) + \text{c.c.}\right]$$

$\widehat{K}, \widehat{W}$ = dimensionless Khaler and superpotential

$$F \sim g_* f^2 \qquad f_a \sim f \qquad w_R \sim g_* f^3 \qquad M_{\text{SUSY}} \sim m_* \sim g_* f \qquad m_a^2 \sim \epsilon_R m_*^2 \ll m_*^2$$

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$$m_{\lambda^i} \sim \frac{g_i^2}{g_*^2}\, m_*$$

gauge mediation-like spectrum with

$$N_{\text{mess}} \simeq \left(\frac{4\pi}{g_*}\right)^2$$

LHC bounds

$$1 \ll g_*^2 \ll (4\pi)^2$$

Large NDA anomalies

Higgs mass & EWSB, sfermion masses, … another time

Phenomenology I: production

GUT-inspired gaugino masses $m_{\tilde{B}} \simeq 500\ \text{GeV}$ $m_{\tilde{W}} \simeq 1\ \text{TeV}$ $m_{\tilde{g}} \simeq 2.5\ \text{TeV}$

Outside reach of LHC13!

Would correspond to $m_* \simeq 22\ \text{TeV} \left(\frac{g_*}{3}\right)^2$

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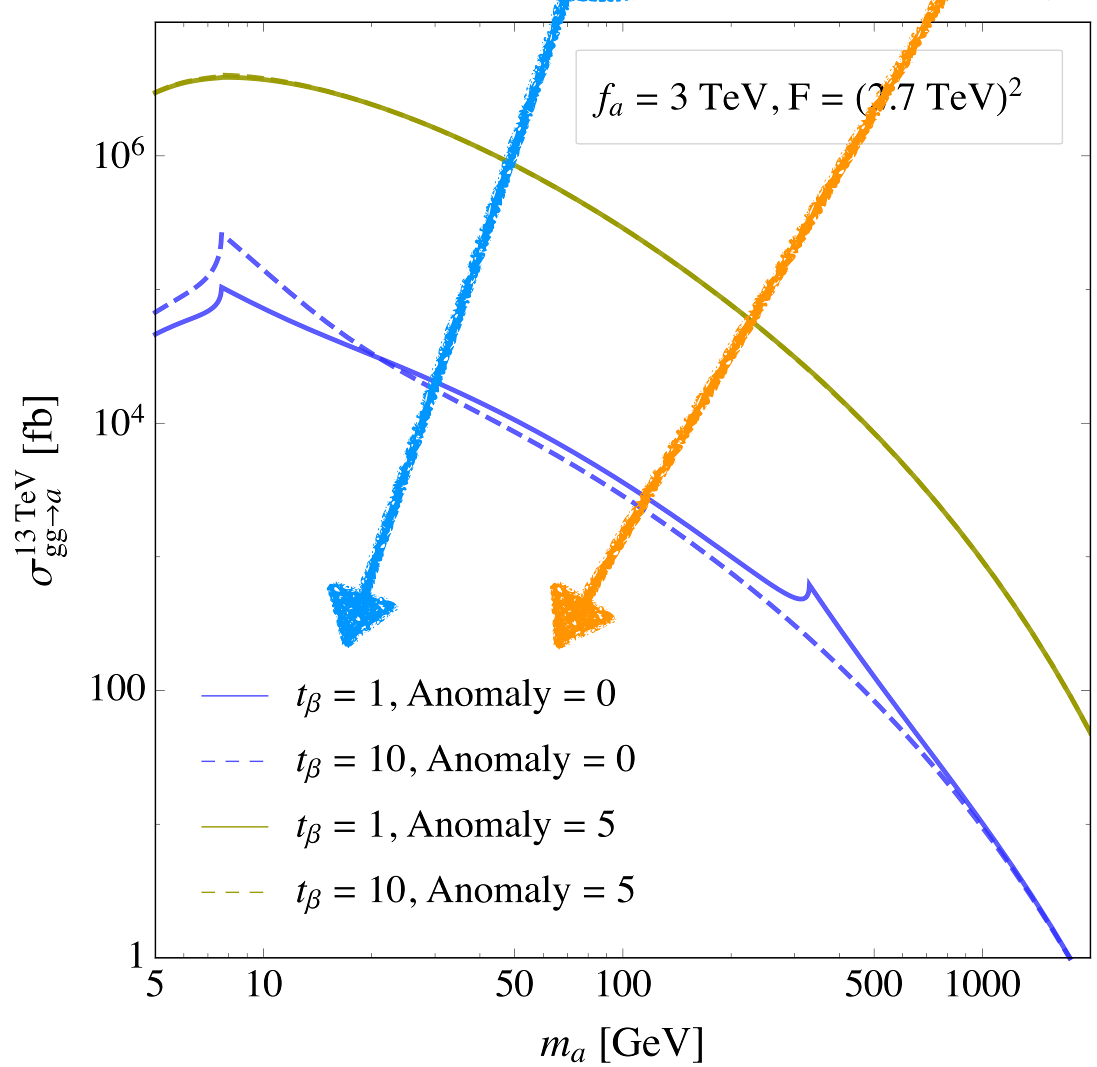
gluino loop t & b loops UV anomaly



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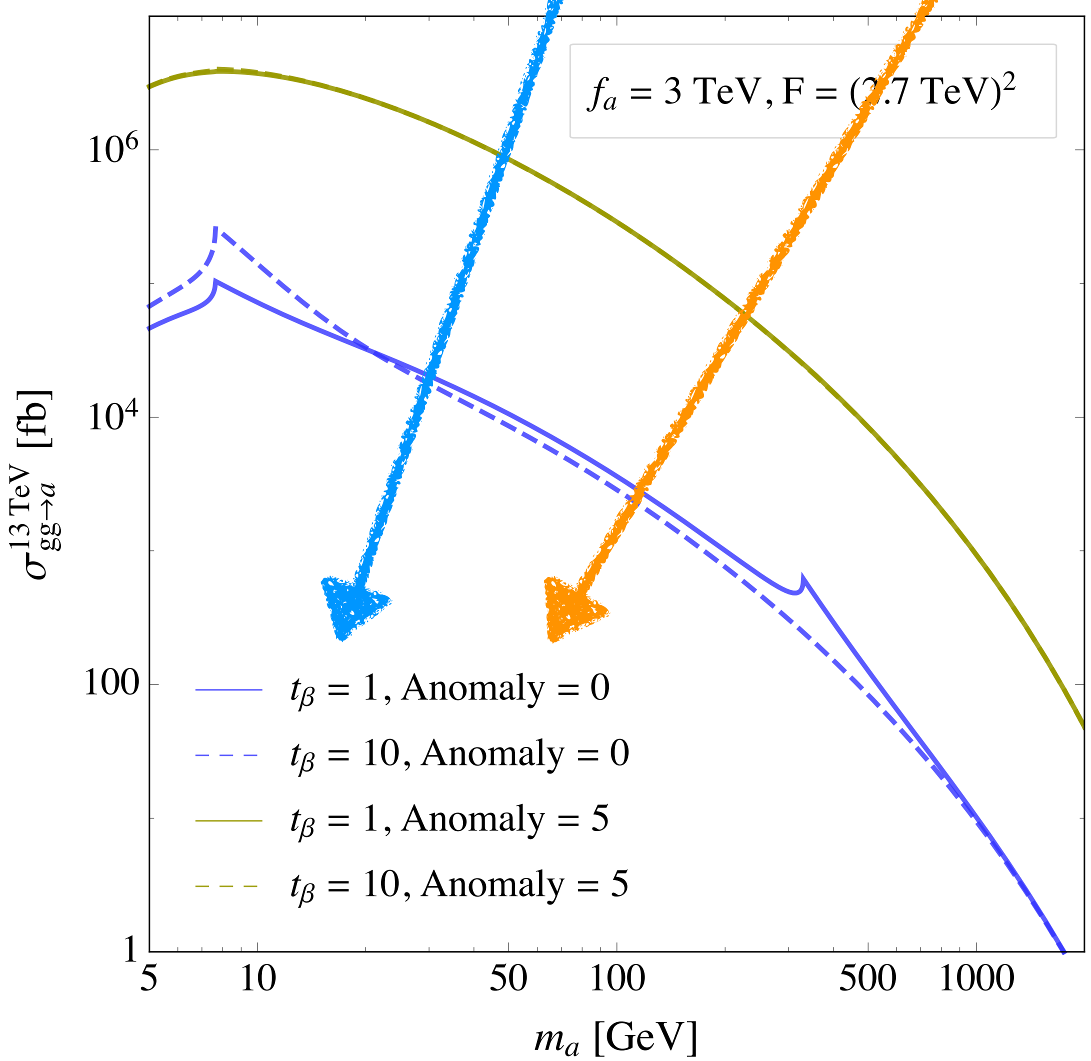
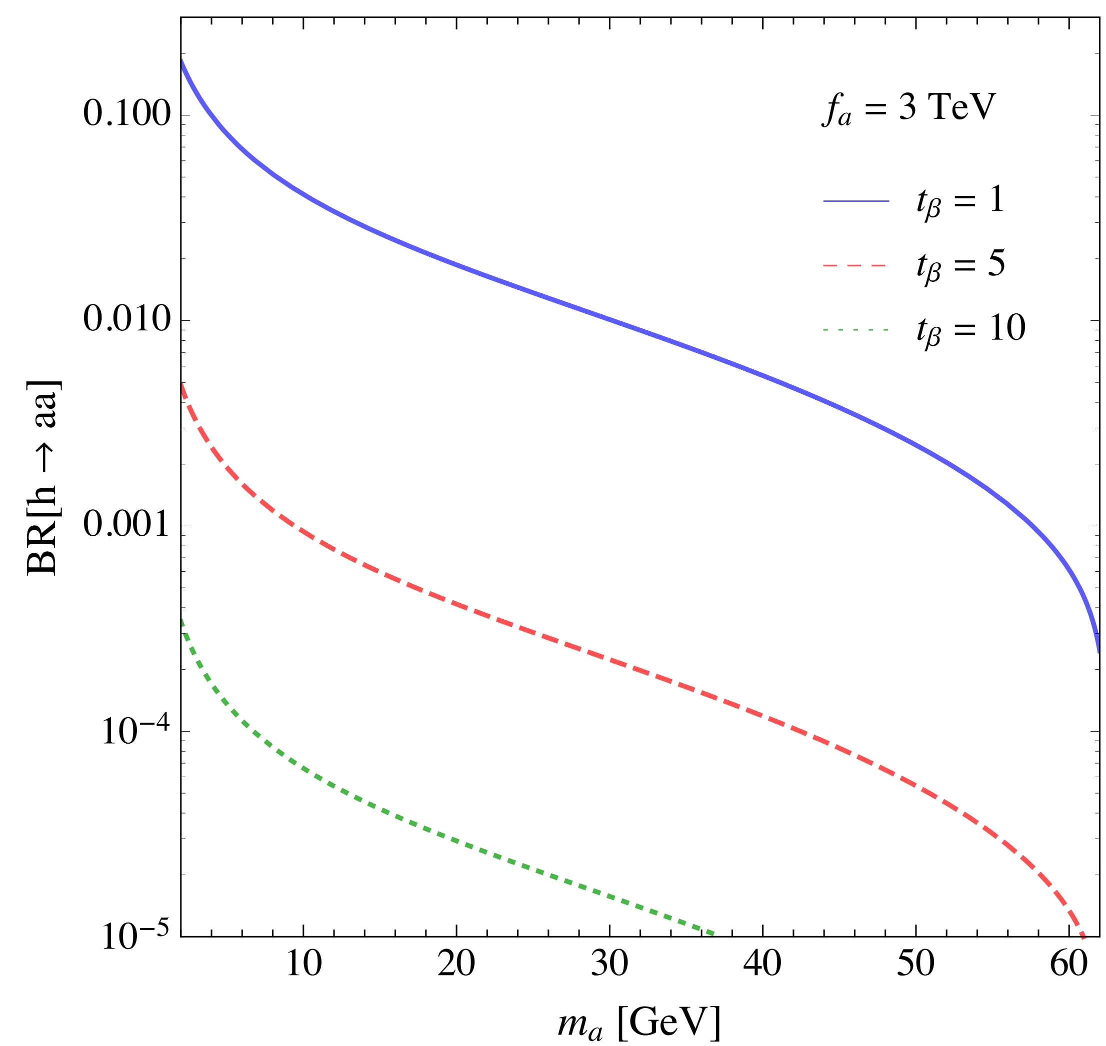
$h \to aa$

depends on $\delta = R_H \frac{v}{f_a} \frac{s_{2\beta}}{2}$





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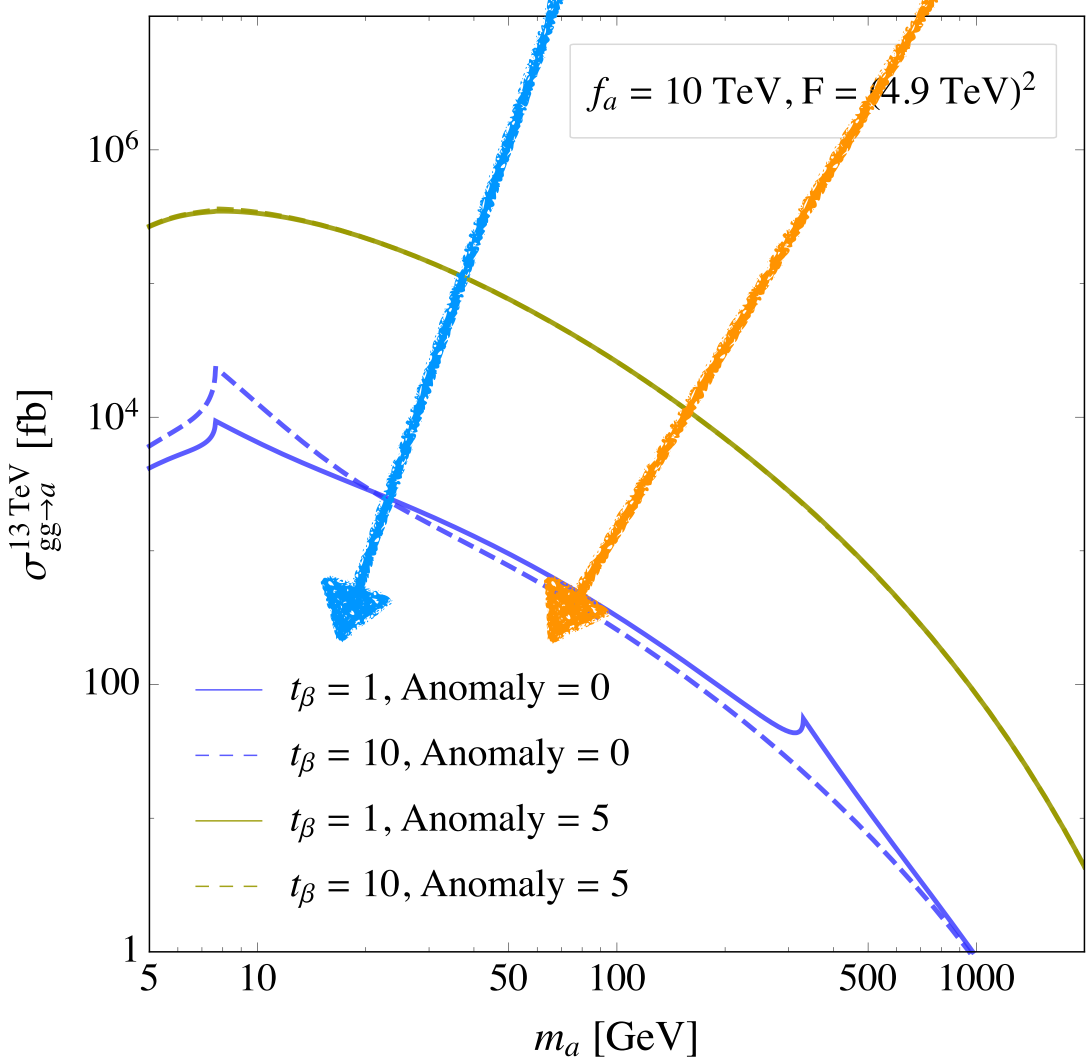
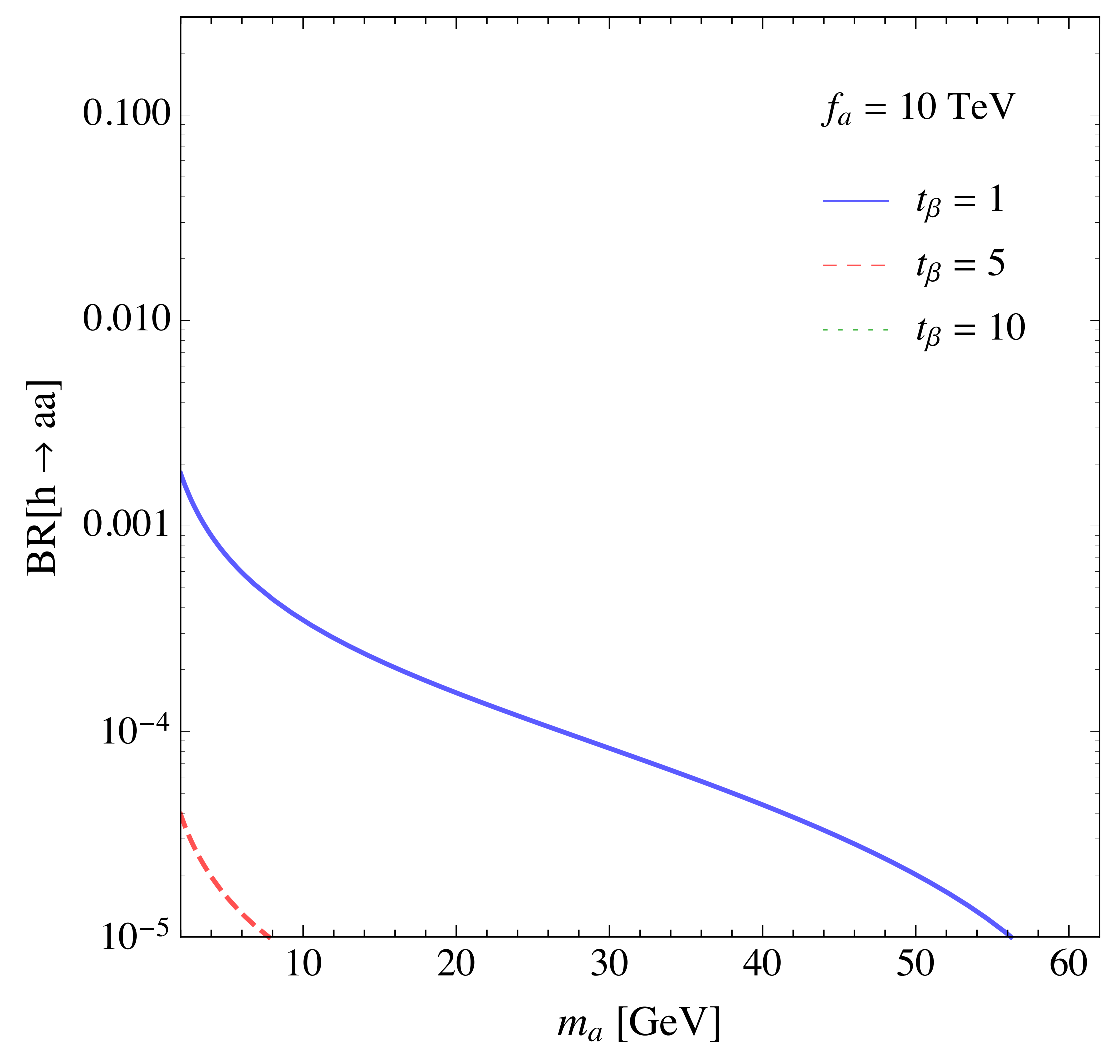
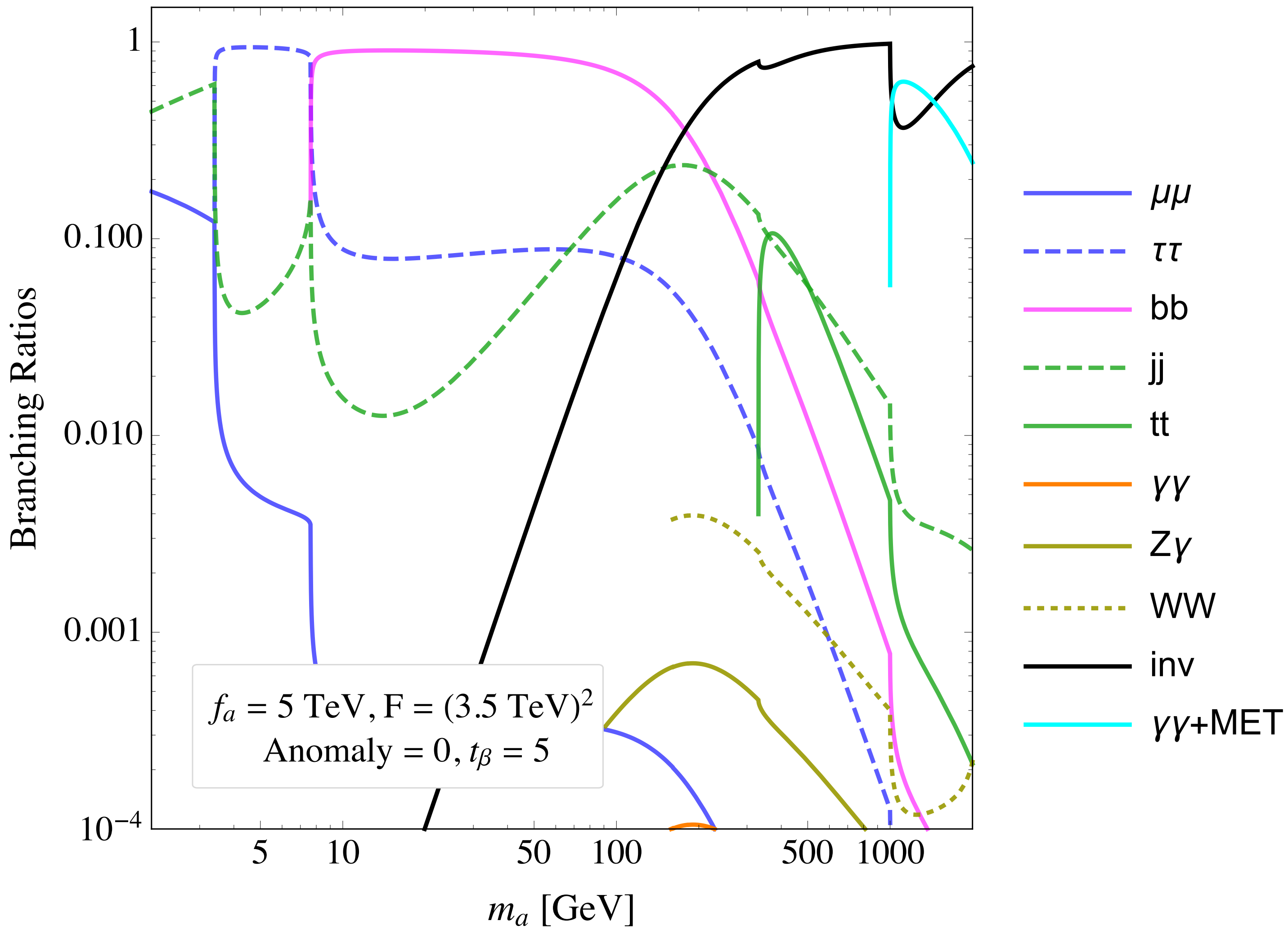




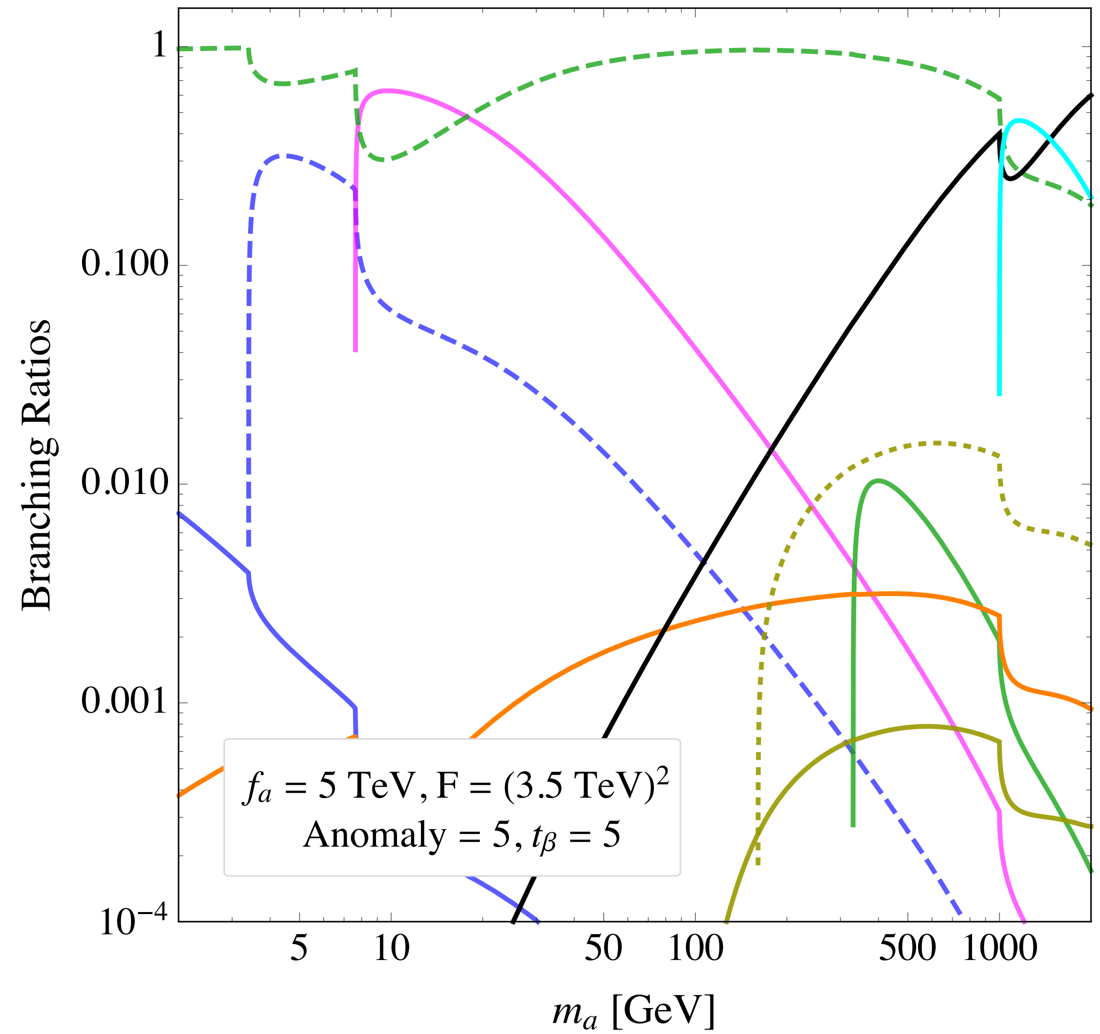
Phenomenology II: decays

Both plots: $t_\beta = 5$

No anomaly



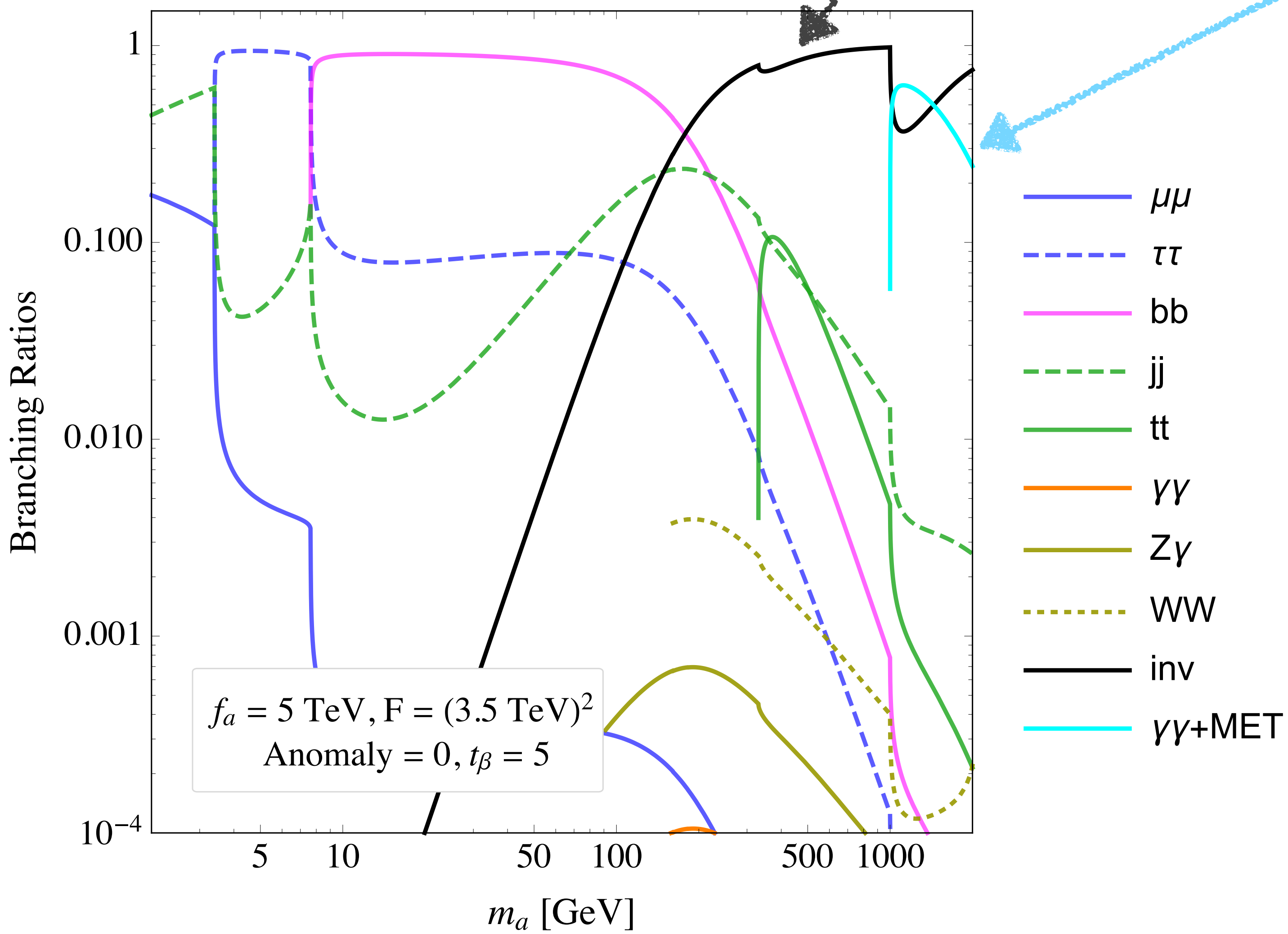
Large anomalies

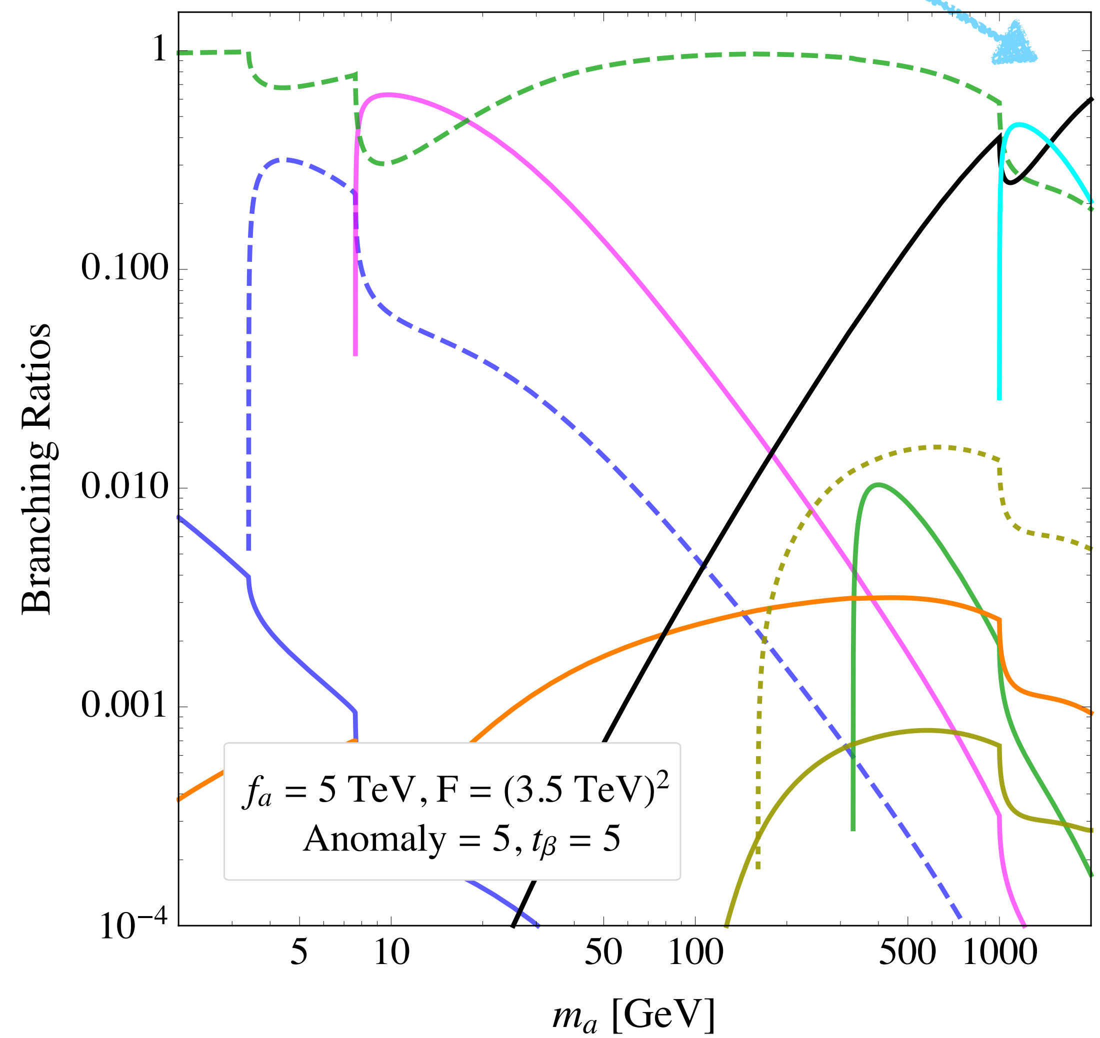


Phenomenology II: decays

MET from decays into gravitinos

$a \to \tilde{B}\tilde{B} \to \gamma\gamma + \mathrm{MET}$





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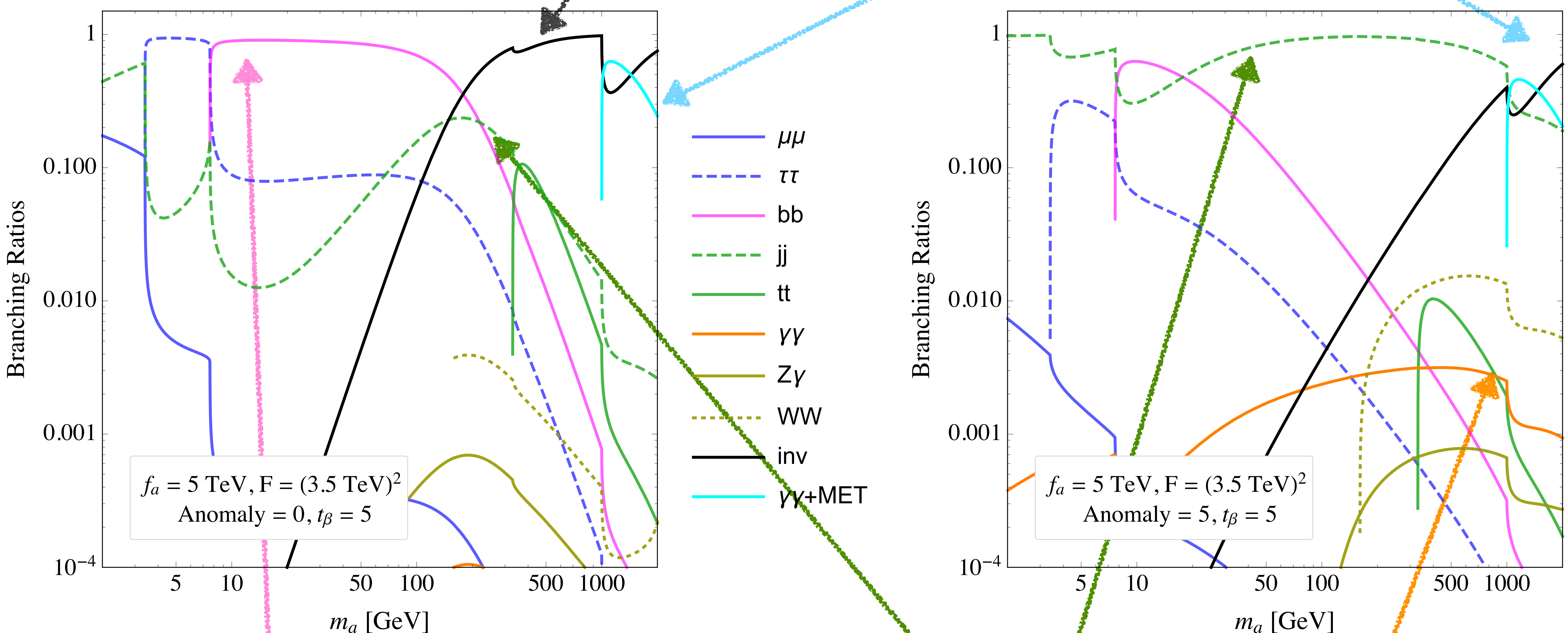


$\mu\mu \quad \tau\tau \quad bb$

dijet

diphoton

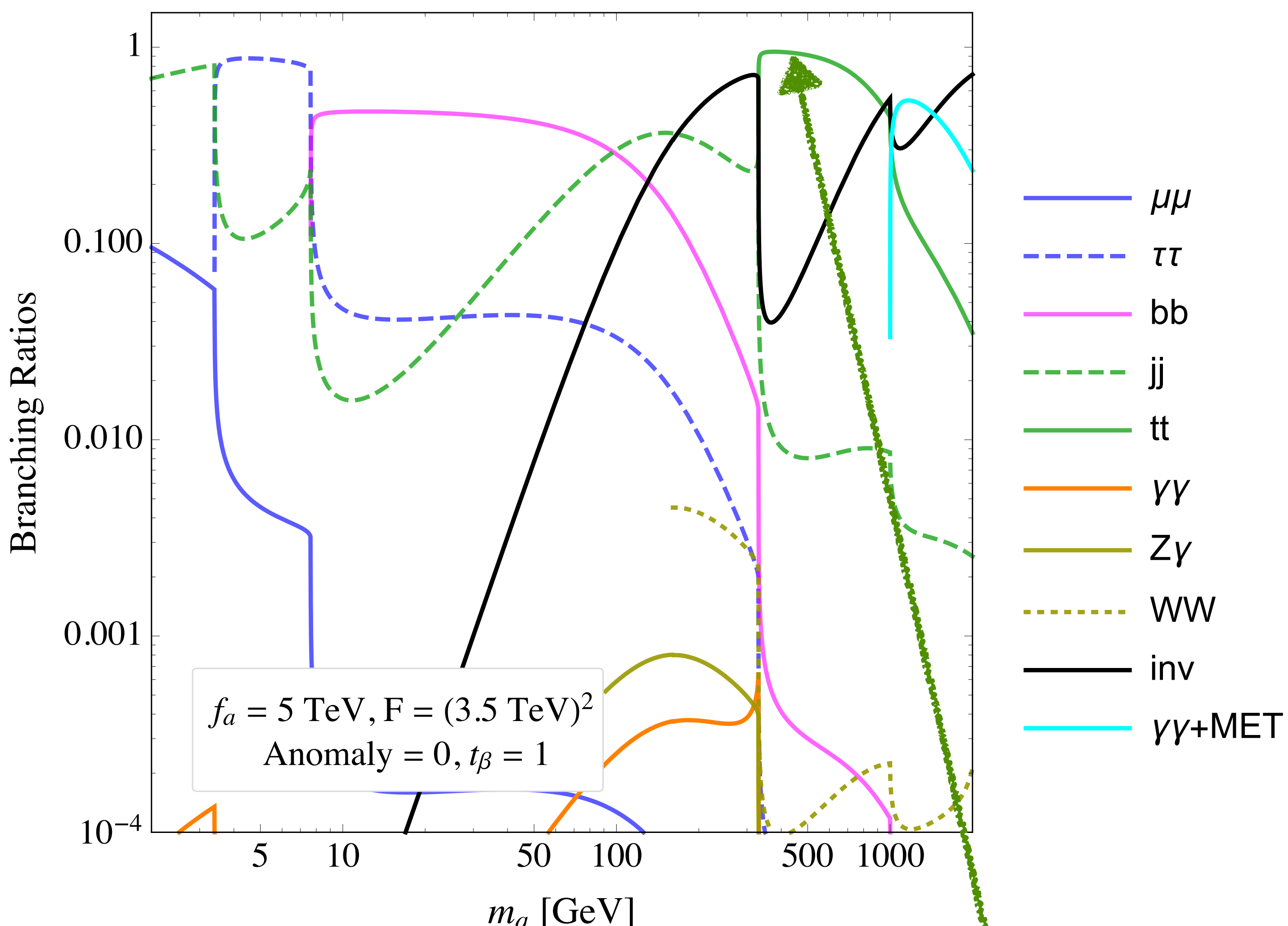
more important for small anomalies

more important for large anomalies

Phenomenology II: decays

Both plots: $t_\beta = 1$

No anomaly



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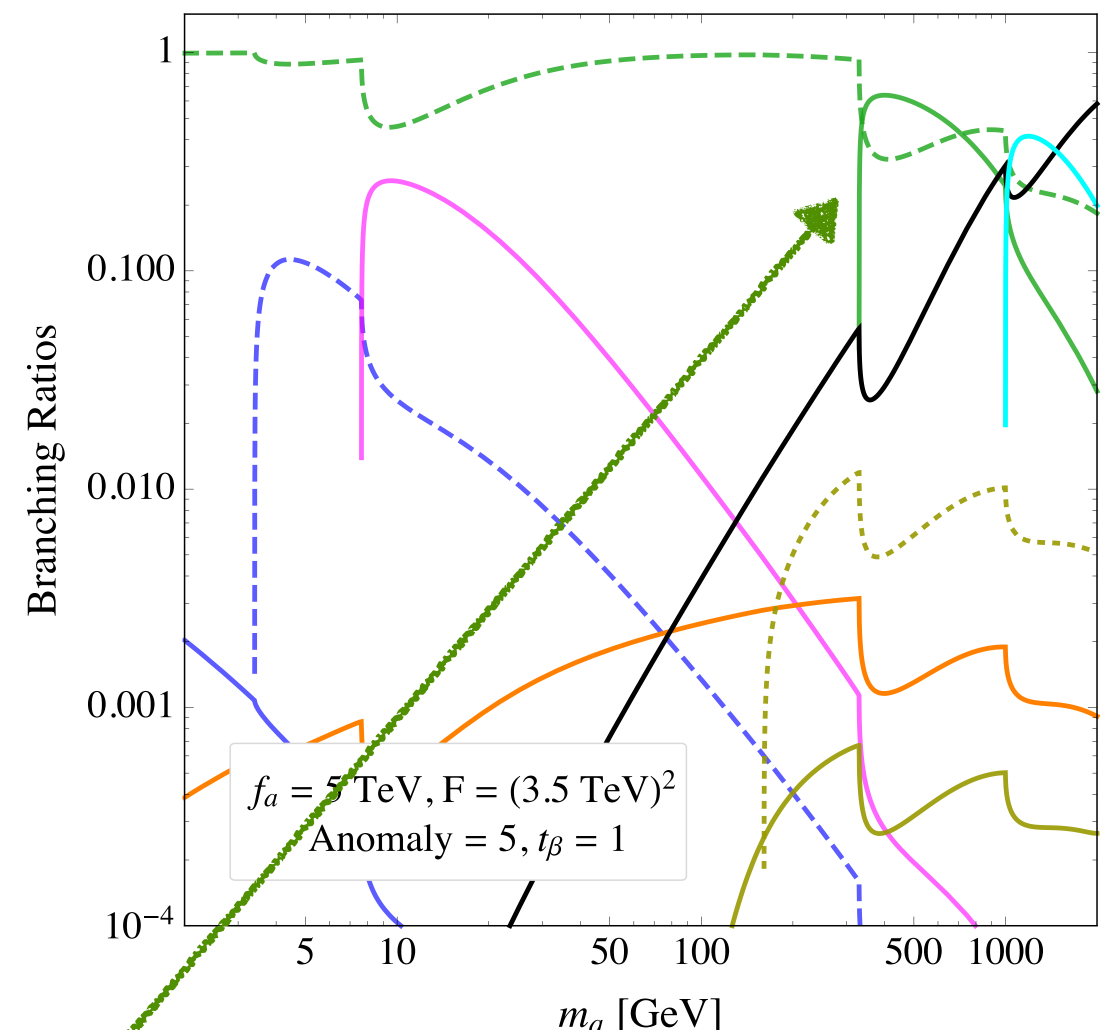


tt becomes more important!

see e.g. Craig et al. 1504.04630

$\Gamma_a/m_a < 10^{-3}$ so interference with SM in tt should not give problems…

Example: heavy a within a UV model

m_*

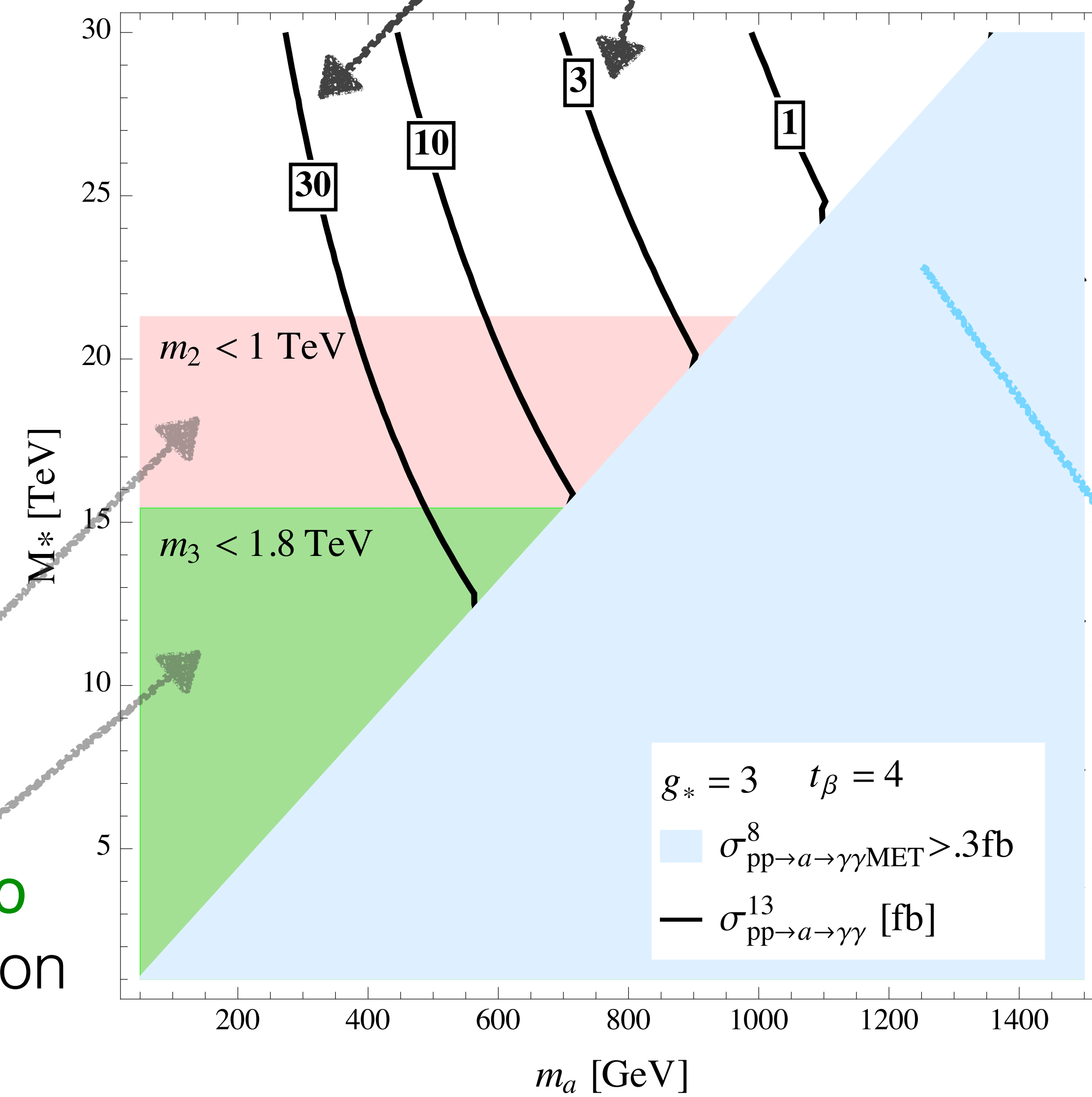
$m_{\text{soft}} \approx \dfrac{g^2}{g_*^2} m_*$

$m_a \approx \epsilon_{\not{R}} m_*$

$m_G = \dfrac{F}{\sqrt{3} M_{Pl}}$

$\sigma^{\text{LHC13}}_{pp\to a\to\gamma\gamma}$ [fb]

R-axion first appears as narrow resonance in diphoton!



Wino & gluino pair production

$a \to \gamma\gamma + \text{MET}$

excludes signals down to 0.3 fb @LHC8

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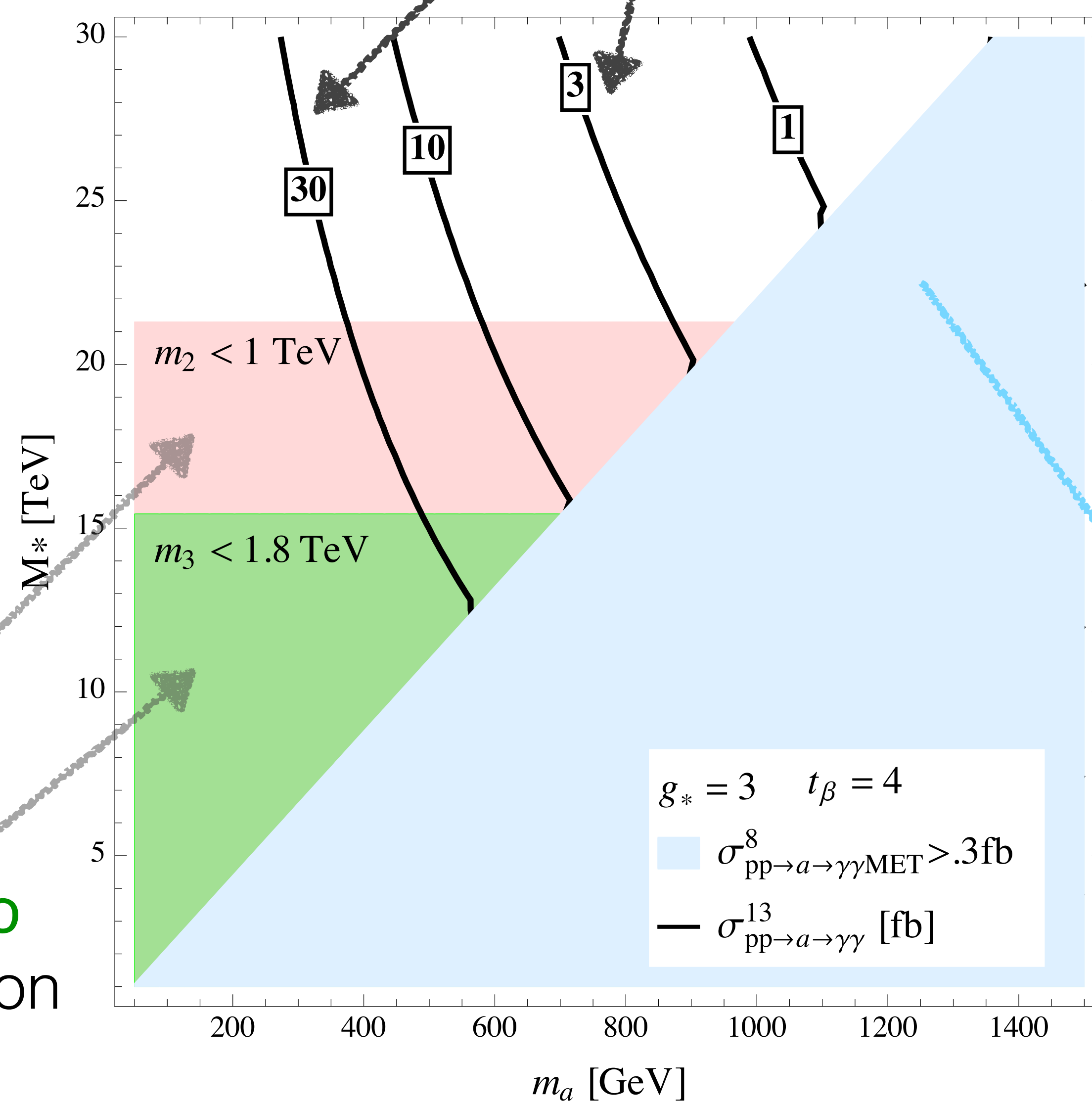

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How to know it is R-axion and not another scalar?

Hint: other peculiar decays like MET; pattern of signals

Observe other SUSY & correlate parameters

Summary and outlook

Bellazzini Mariotti Redigolo FS Serra, in progress

Spontaneously broken R-symmetry is quite generic

provides a naturally light hidden sector state, the **R-axion**

This state could be the first sign of SUSY at the LHC

when superpartners are heavy! (strong coupling, split,…)

LHC pheno: ~ in between a heavy axion and an MSSM-like CP-odd

adds motivation to LHC (heavy & light) scalar searches!

Future more model building (e.g. split SUSY? models for m_a?)

pheno other than LHC (e.g. cosmo?)

….

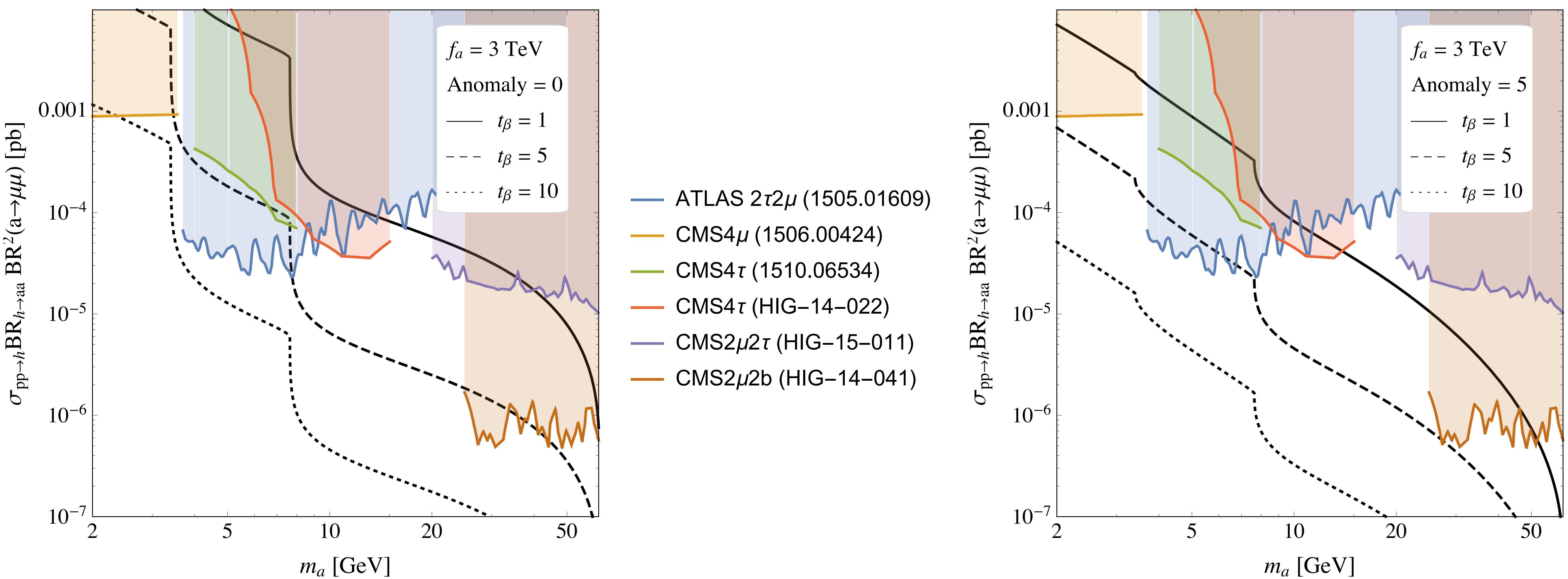
Back-up slides

Example: light pseudoscalar

Both plots: $f_a = 3\ \mathrm{TeV}$

No anomaly

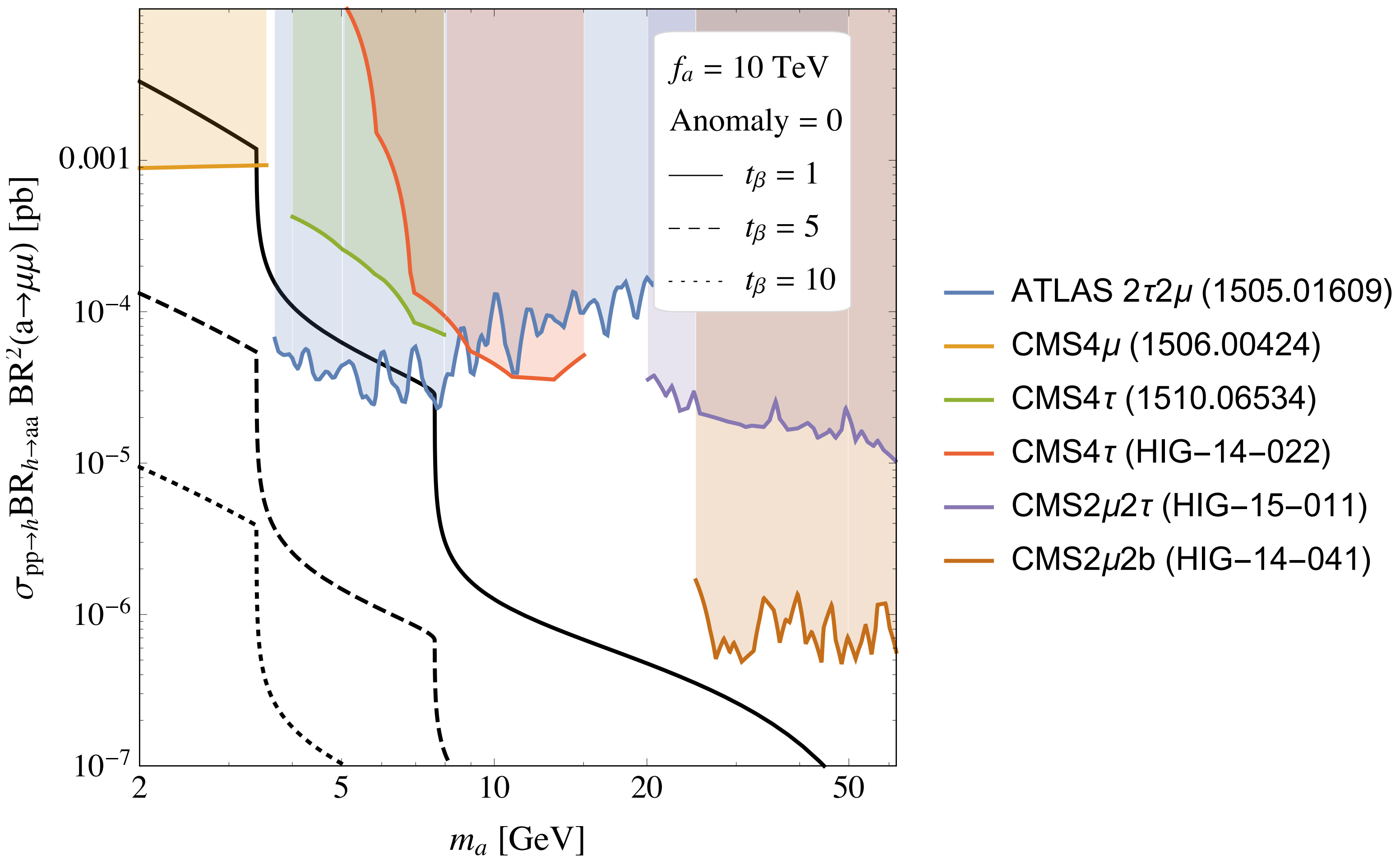
Large anomalies



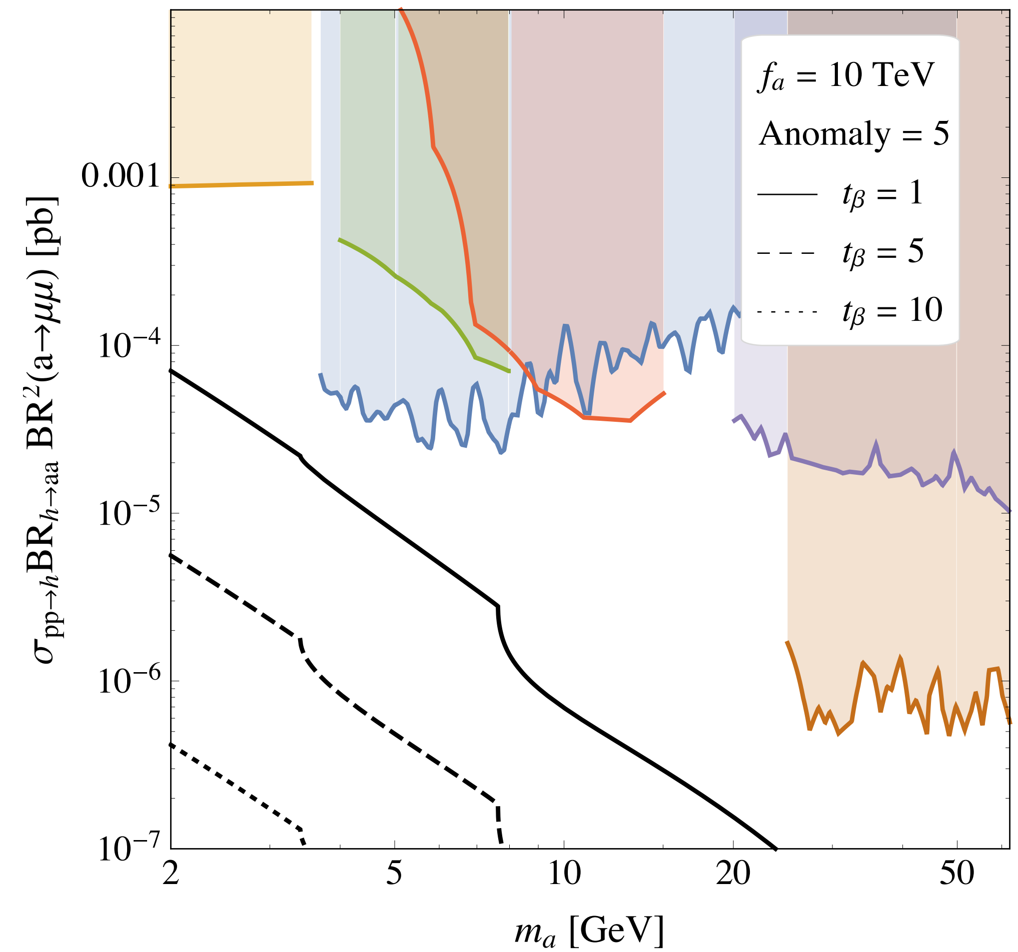
Example: light pseudoscalar

Both plots: $f_a = 10\ \mathrm{TeV}$

No anomaly



Large anomalies



R-axion width