Future of BSM and top

G.Cacciapaglia (IP2I Lyon)
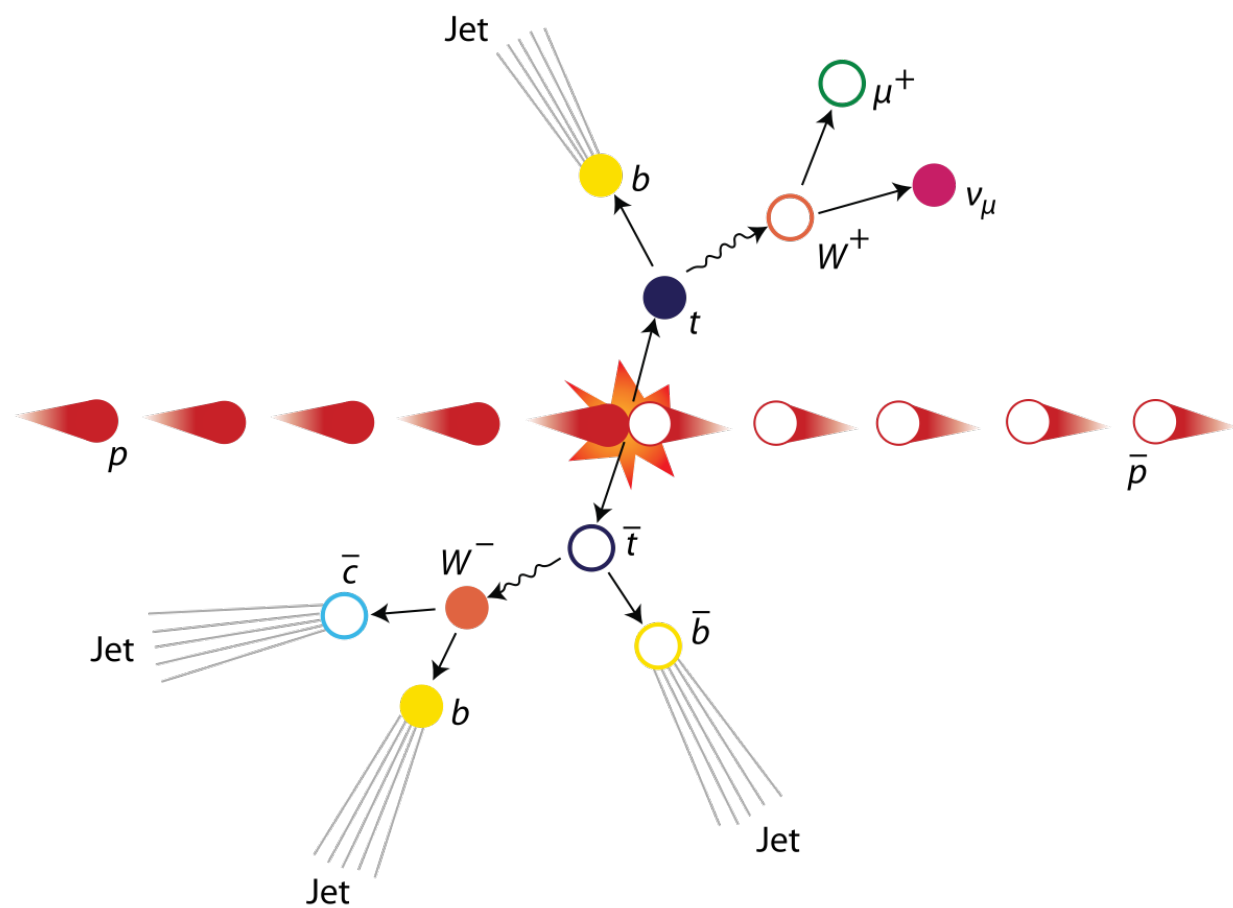
Zoom, 06/04/2021

Top-LHC-France 2021

Labex
LIO
Institut des Origines de Lyon

iP2i
LES 2 INFINIS
LYON

UNIVERSITÉ DE LYON
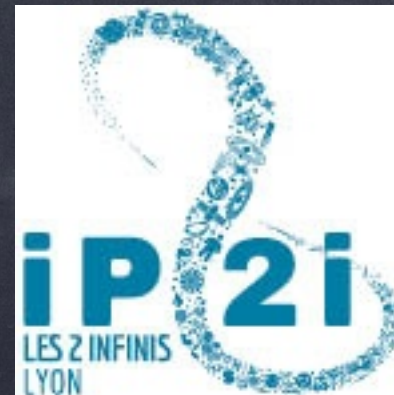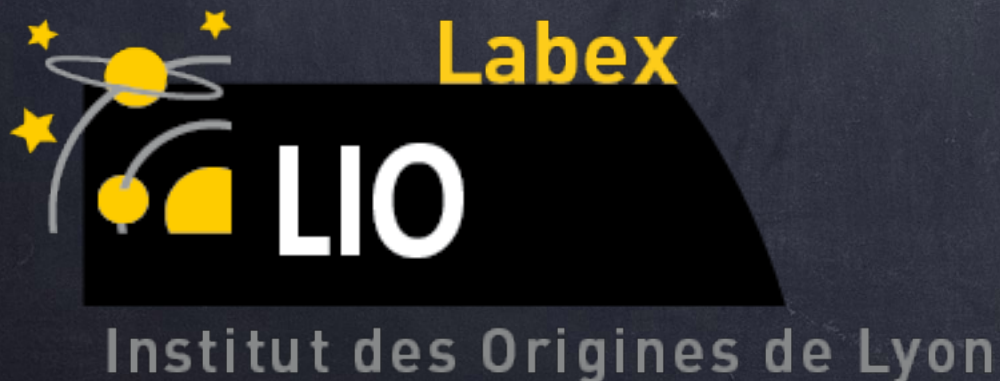
Why BSM and top?

- The top quark is the heaviest known (elementary) particle
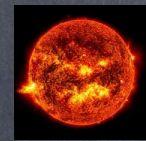
Why BSM and top?

- The top quark is the heaviest known (elementary) particle

  In perspective, if the sun...

The Sun

Top ← Proton

$M \approx 171 \, M_\odot$

Star in the R136a cluster in the Tarantula Nebula

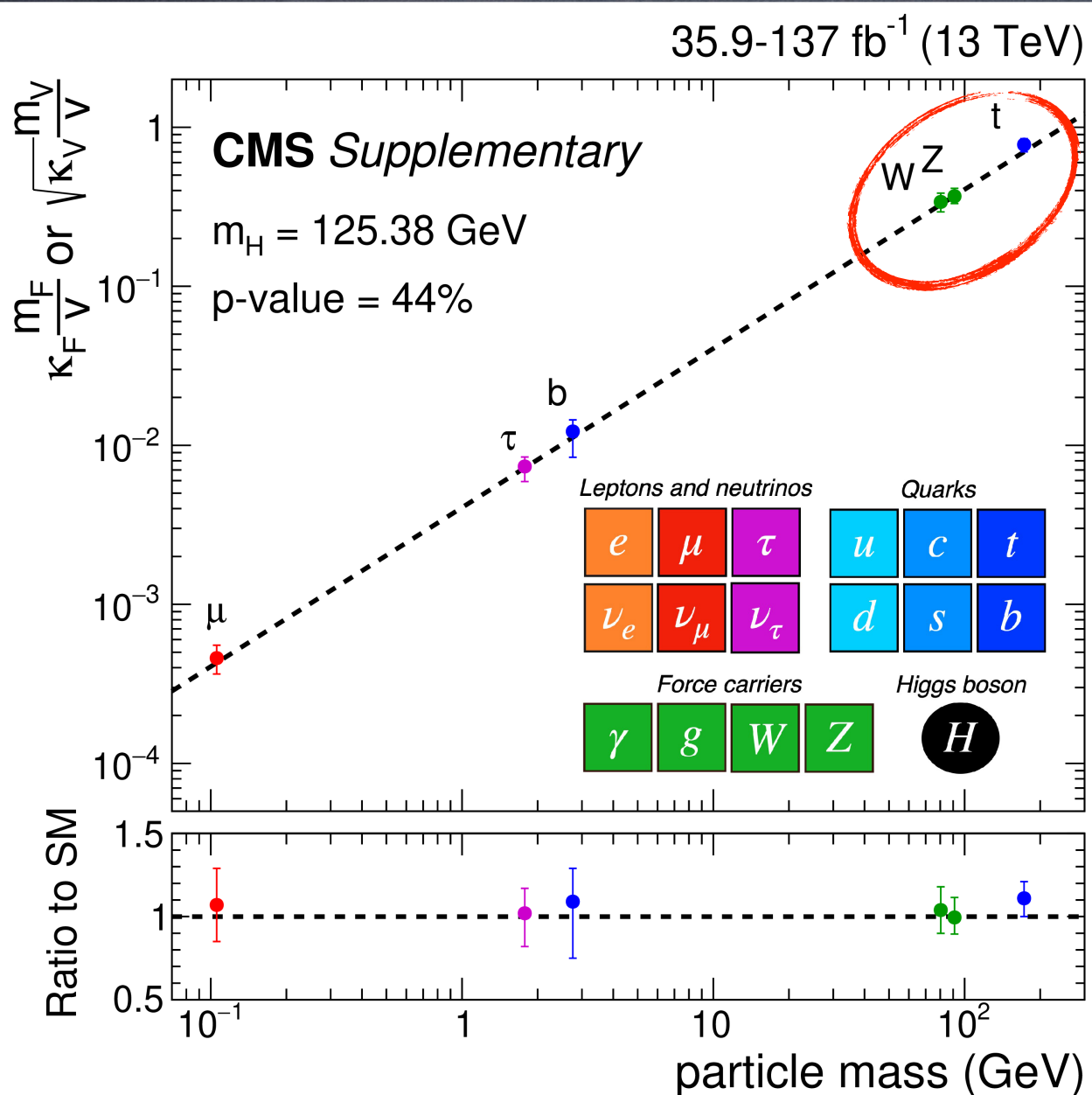- Wolf-Rayet star, the most unusual star type.

COINCIDENCE?

I THINK NOT

Why BSM and top?

- The top quark is the heaviest known (elementary) particle

Only fermion with O(1) couplings to the Higgs boson (EWSB).

Must play a role in BSM physics addressing the EWSB mechanism!

Why BSM and top?

- "Carneade! Chi era costui?"

- Who is, really, the top?

Is the top just an ordinary quark?

What is the nature of the top?

Why so much heavier than the other fermions?

What is hiding behind the top?

Don Abbondio, "I promessi sposi", chapter VIII

Why BSM and top?

- "Carneade! Chi era costui?"

- Who is, really, the top?

Summary of the talk:

1) Tell me what you decay into, and I'll tell you who you are!

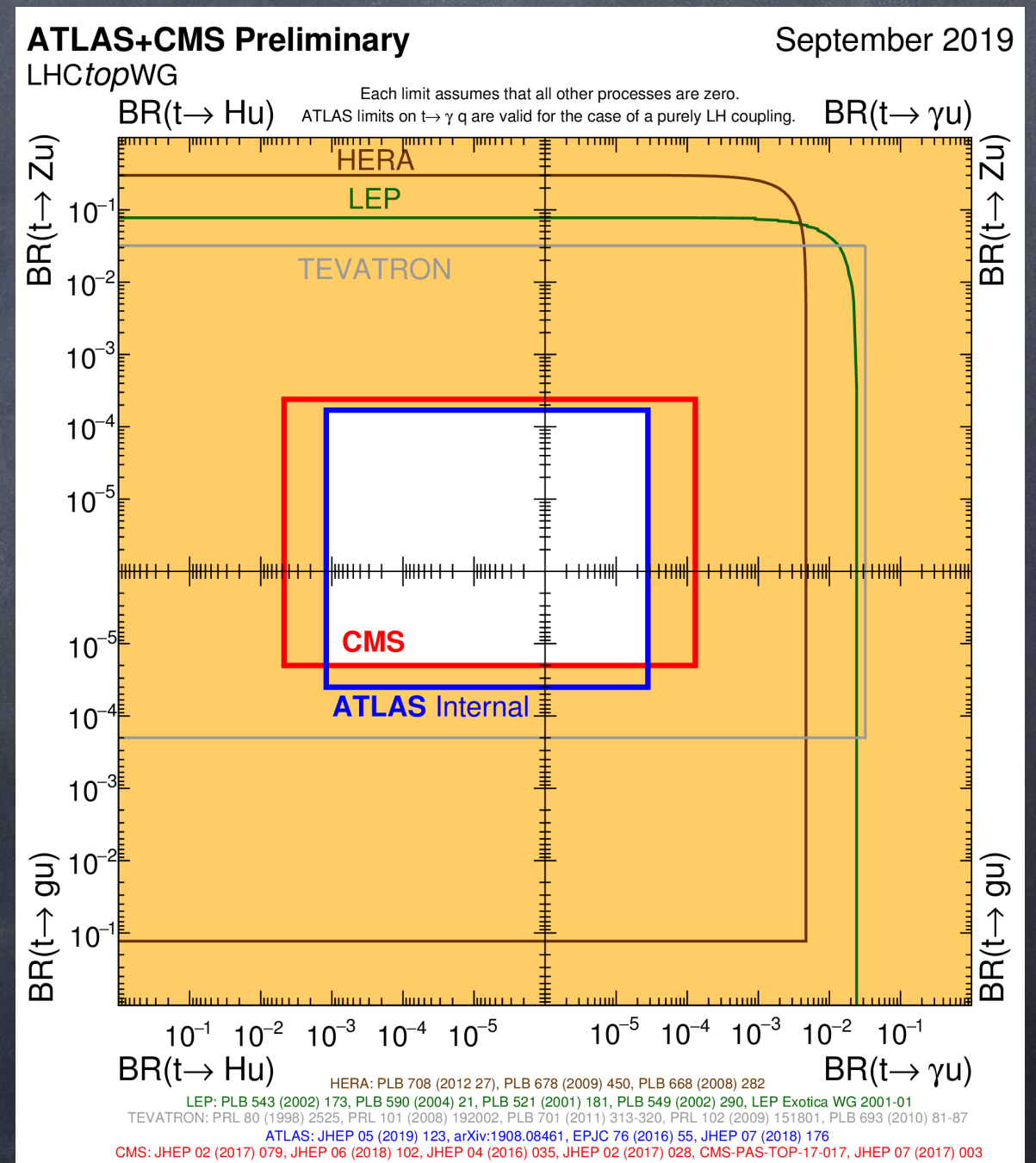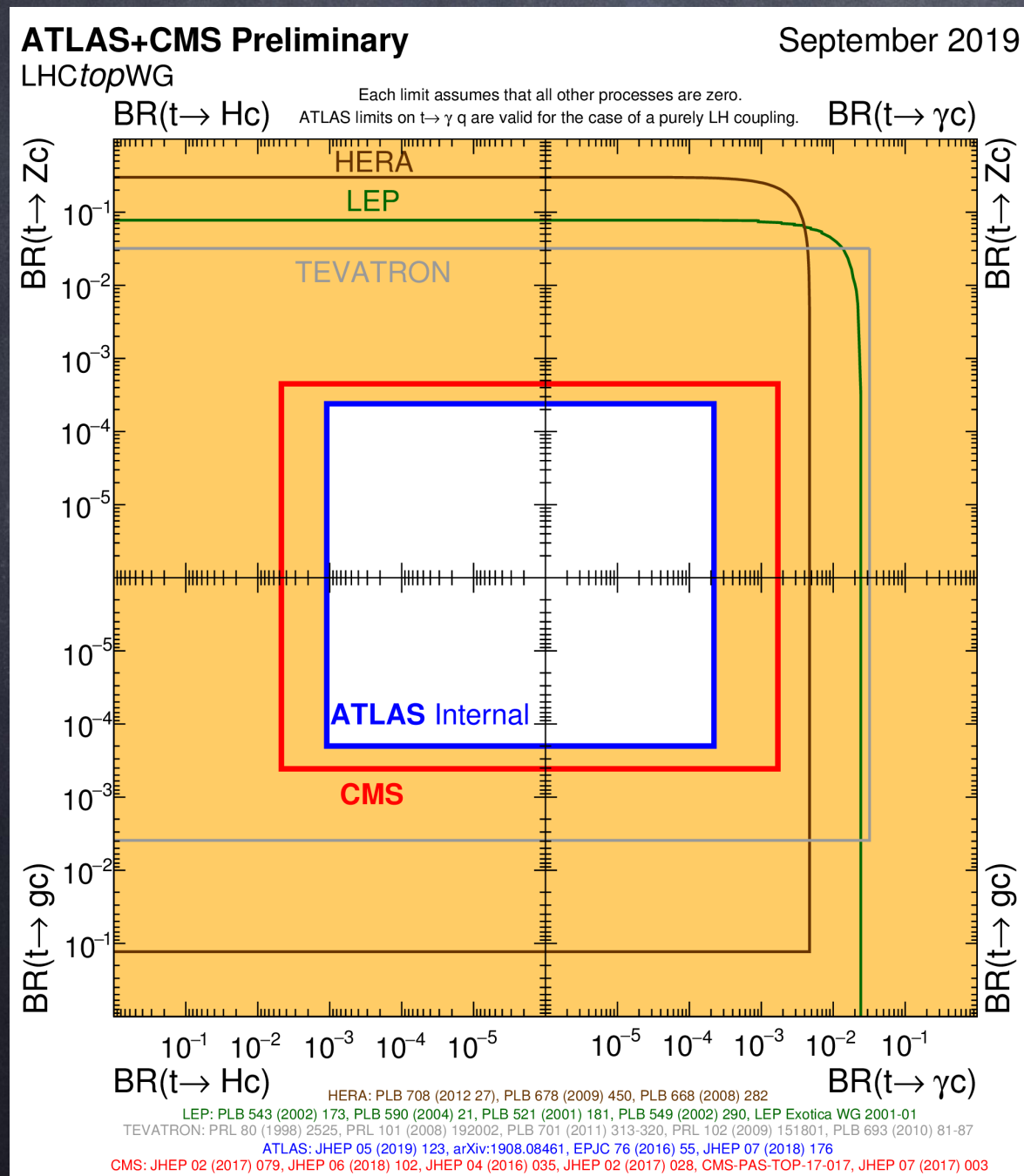2) Coupling therapy: how does it couple to the rest of the SM?

3) Better alone, or in "bad" company? What comes along the top quark?
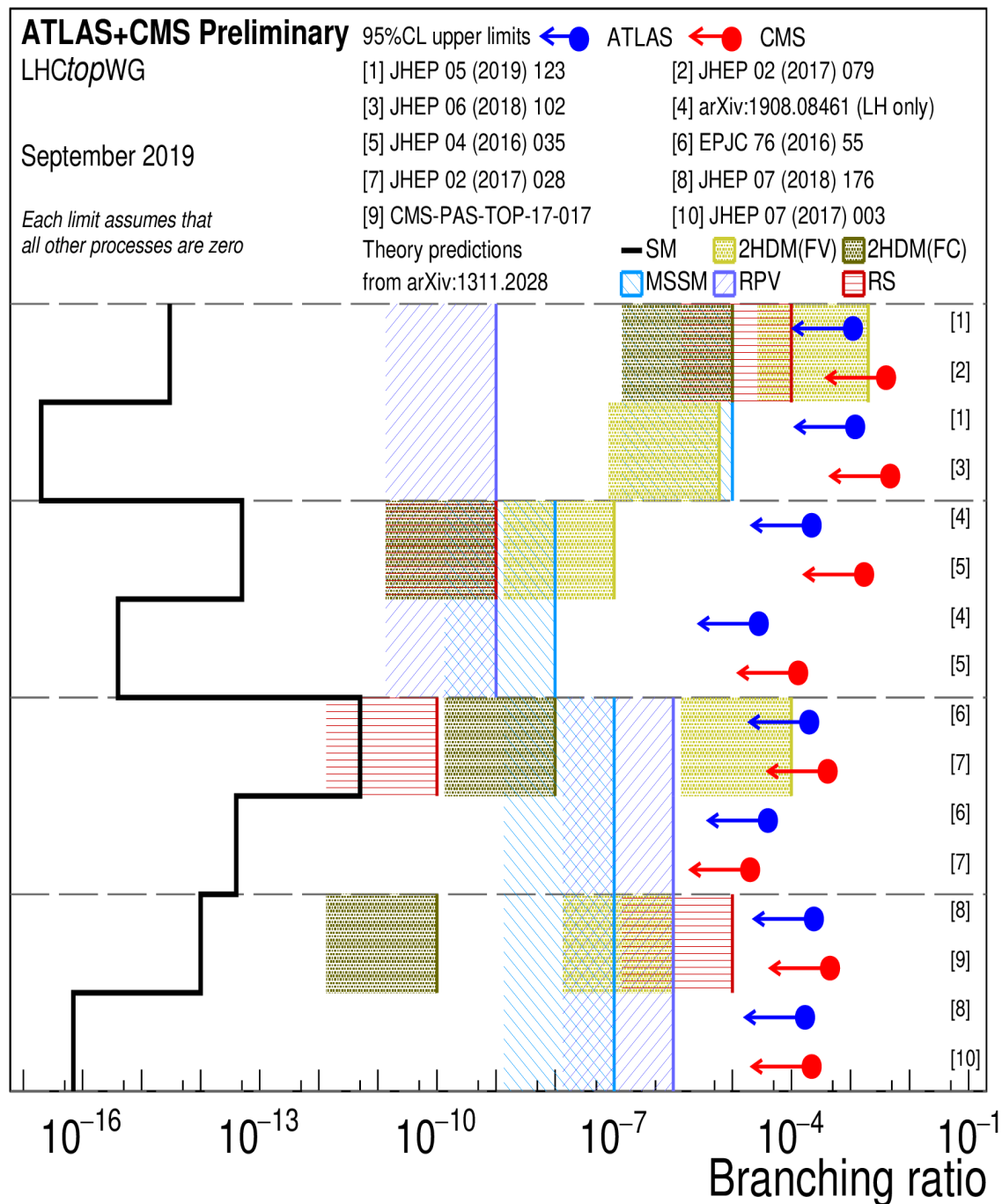

Don Abbondio, "I promessi sposi", chapter VIII

1) Rare top decays

The current status looks already impressive:
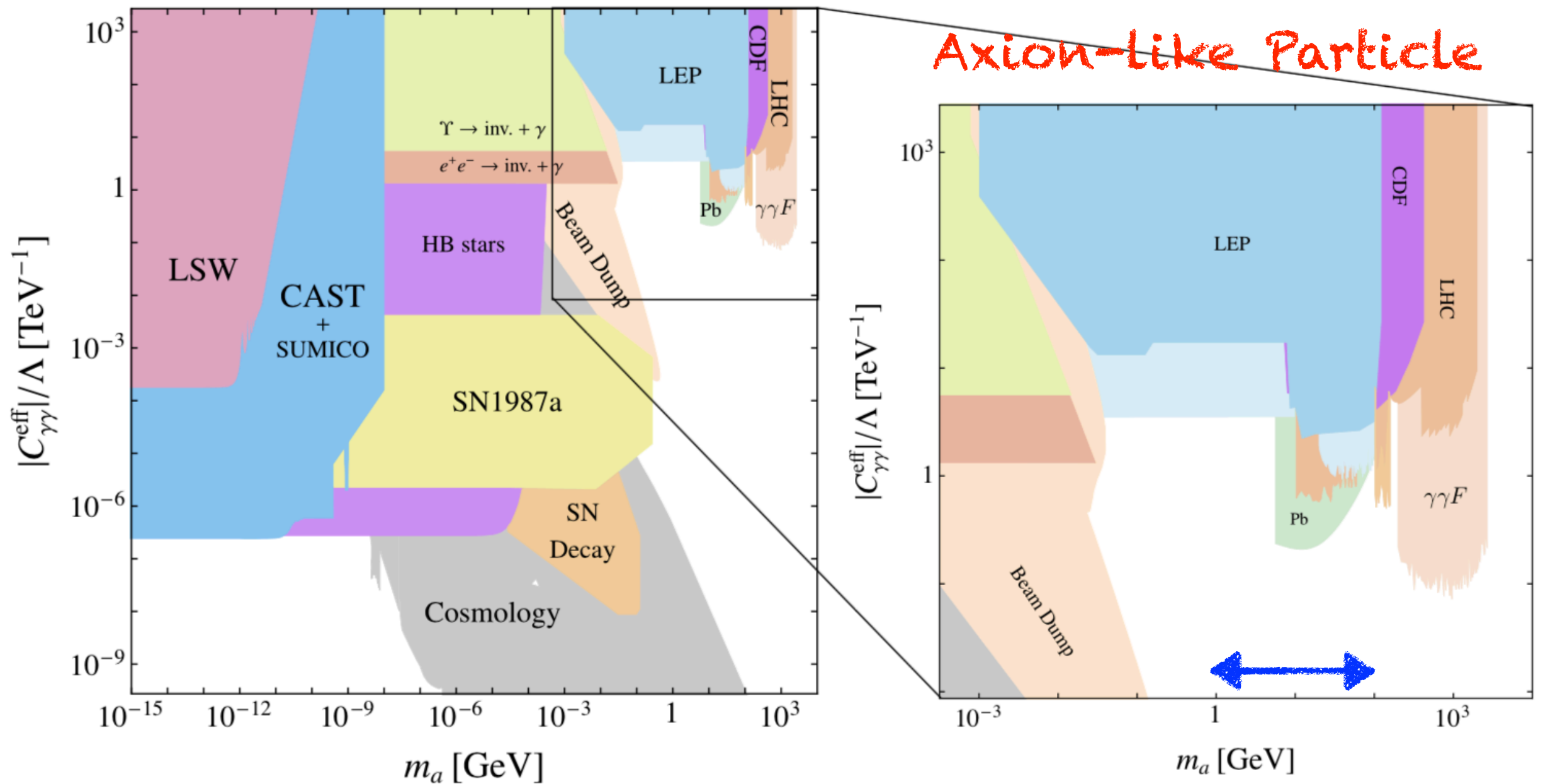
1) Rare top decays

What improvements in the near future?

- Combinations of different channels?

- BSM model expectations need to be updated to current bounds!

- Decays into light BSM states can be included!
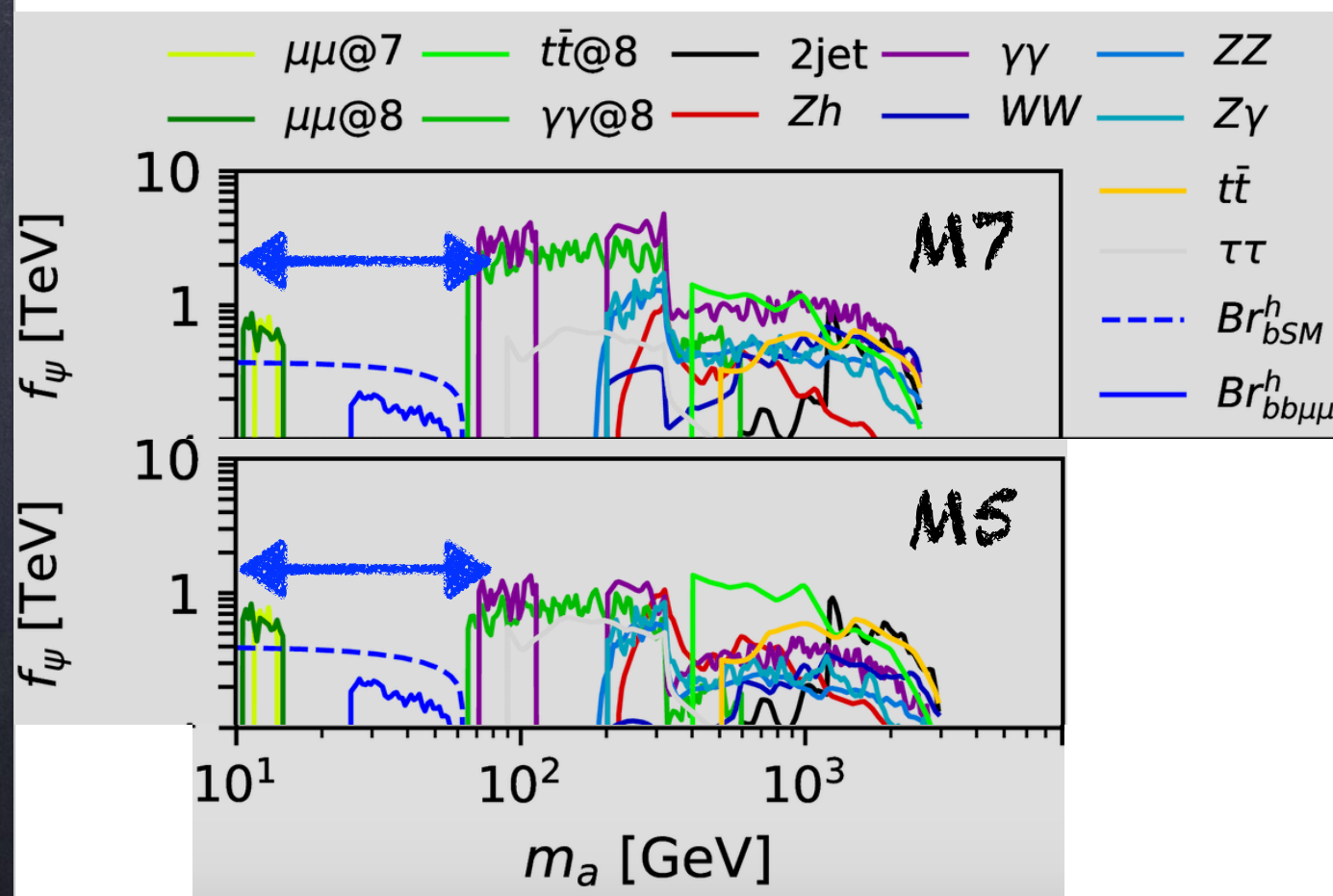
1) Rare top decays
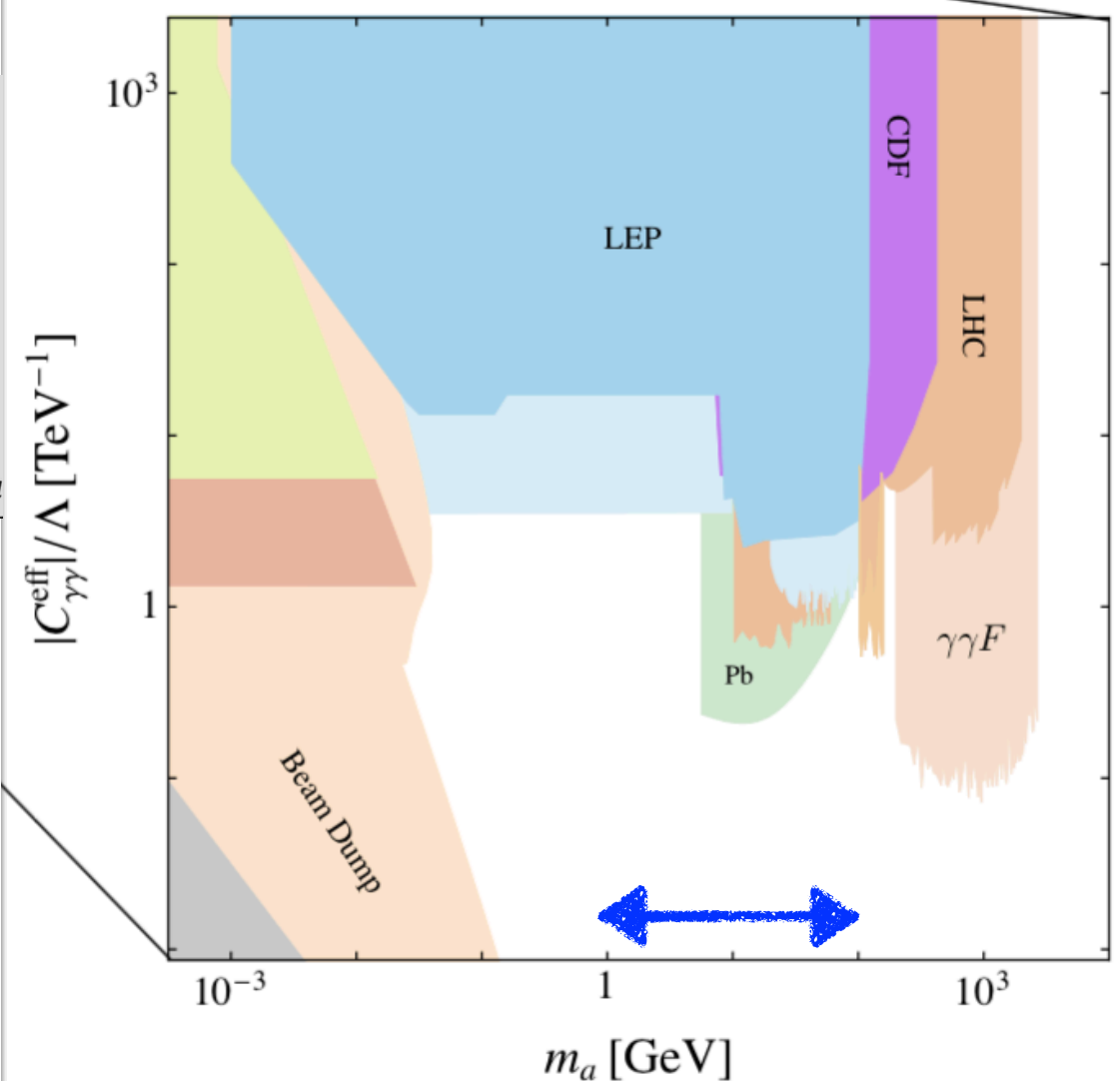
t -> u/c a, where "a" is a light pseudo-scalar

Axion-like Particle

From 1808.10323

1) Rare top decays

t -> u/c a, where "a" is a light pseudo-scalar

Light composite pNGB

Axion-like Particle

From 1902.06890

From 1808.10323

1) Rare top decays

t -> u/c a, where "a" is a light pseudo-scalar

Dominant final states:

$$t \rightarrow u/c\, a \rightarrow \begin{cases} j\,\gamma\,\gamma; & \text{all masses} \\ j\,b\,\bar{b}; & m_a < m_Z \\ j\,Z\,\gamma; & m_a > m_Z \end{cases}$$
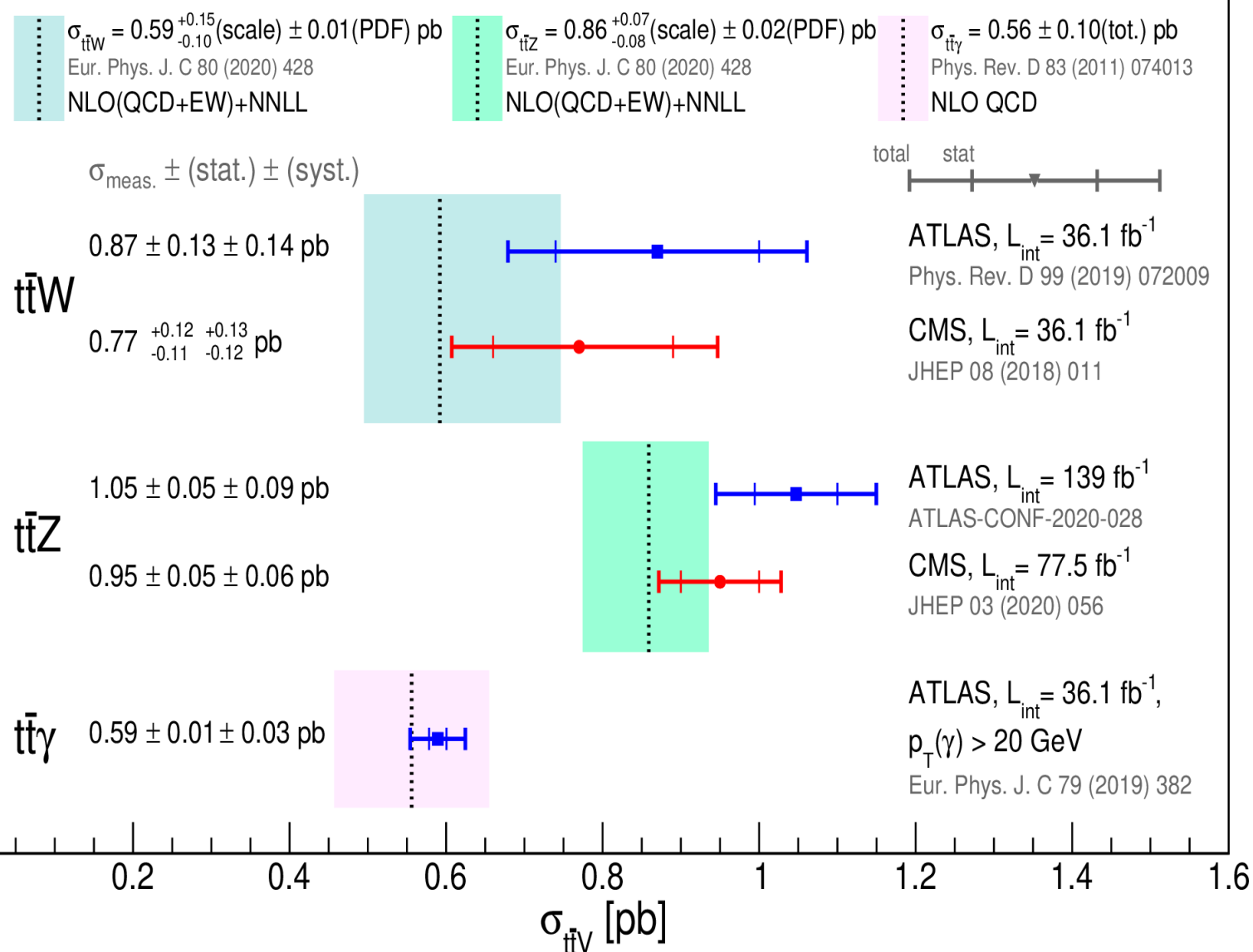
Note: different final states can distinguish
the models behind the singlet a!

2) Top EW couplings

- EW couplings crucial to id the top as an elementary quark, like the others.

ttZ is the only access to the Z couplings we have so far.

ATLAS+CMS Preliminary
LHC*top*WG

$\sqrt{s}$ = 13 TeV, September 2020

$\sigma_{t\bar{t}W} = 0.59^{+0.15}_{-0.10}$(scale) $\pm$ 0.01(PDF) pb
Eur. Phys. J. C 80 (2020) 428
NLO(QCD+EW)+NNLL

$\sigma_{t\bar{t}Z} = 0.86^{+0.07}_{-0.08}$(scale) $\pm$ 0.02(PDF) pb
Eur. Phys. J. C 80 (2020) 428
NLO(QCD+EW)+NNLL

$\sigma_{t\bar{t}\gamma} = 0.56 \pm 0.10$(tot.) pb
Phys. Rev. D 83 (2011) 074013
NLO QCD

total   stat

$\sigma_{meas.} \pm$ (stat.) $\pm$ (syst.)

t̄tW

0.87 $\pm$ 0.13 $\pm$ 0.14 pb
ATLAS, L_{int} = 36.1 fb^{-1}
Phys. Rev. D 99 (2019) 072009

0.77 $^{+0.12}_{-0.11}$ $^{+0.13}_{-0.12}$ pb
CMS, L_{int} = 36.1 fb^{-1}
JHEP 08 (2018) 011

t̄tZ

1.05 $\pm$ 0.05 $\pm$ 0.09 pb
ATLAS, L_{int} = 139 fb^{-1}
ATLAS-CONF-2020-028

0.95 $\pm$ 0.05 $\pm$ 0.06 pb
CMS, L_{int} = 77.5 fb^{-1}
JHEP 03 (2020) 056

t̄tγ

0.59 $\pm$ 0.01 $\pm$ 0.03 pb
ATLAS, L_{int} = 36.1 fb^{-1},
$p_T(\gamma)$ > 20 GeV
Eur. Phys. J. C 79 (2019) 382

0   0.2   0.4   0.6   0.8   1   1.2   1.4   1.6

$\sigma_{t\bar{t}V}$ [pb]

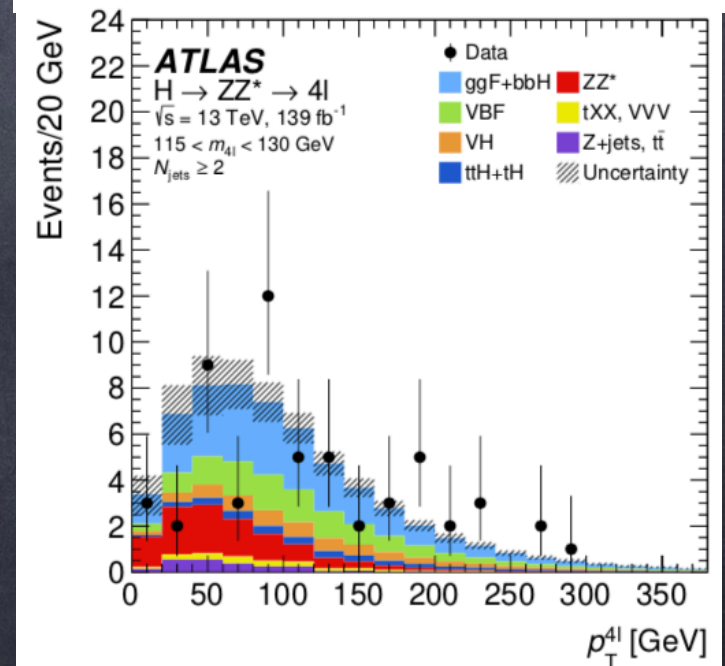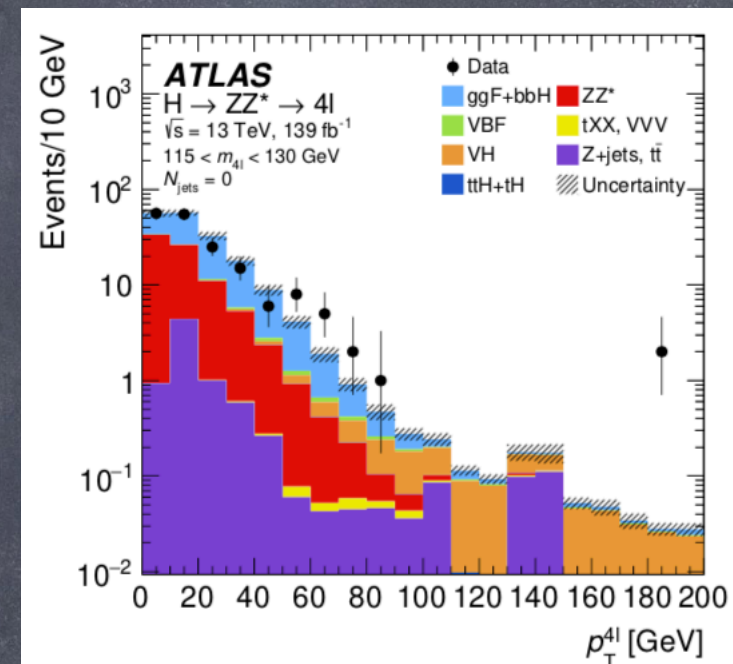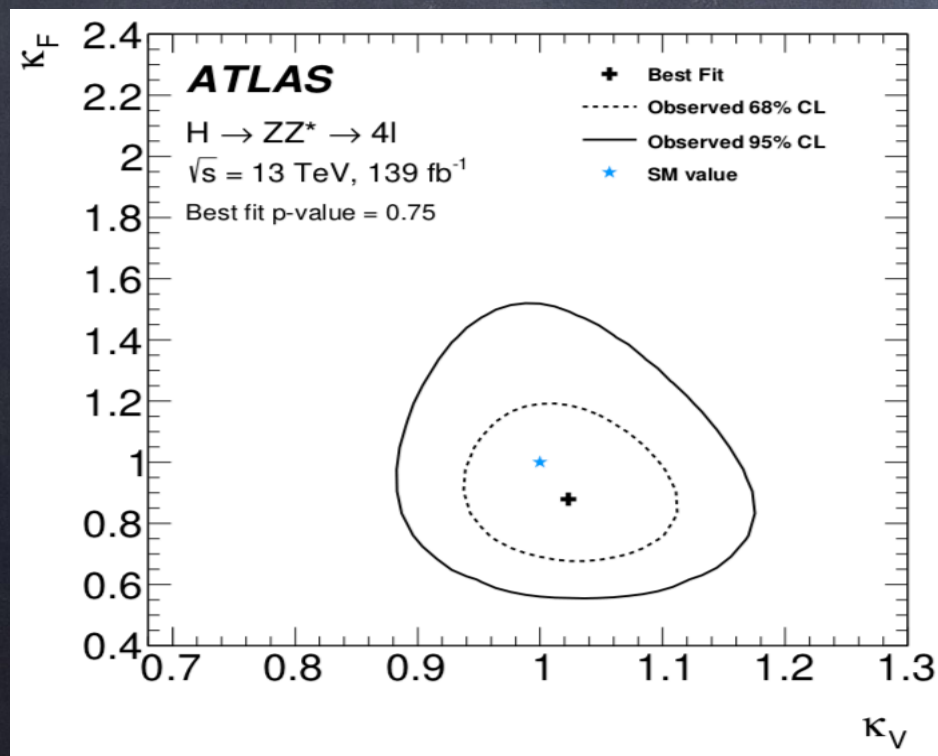# 2) Top EW couplings

- Couplings to the Higgs test the role played by the top in the generation of mass (EWSB)

  Ex: ATLAS w. H -> 4l (2004.03447)

  Direct probe of the top Yukawa

  More statistics allows to probe tails for
  New Physics

2) Top EW couplings

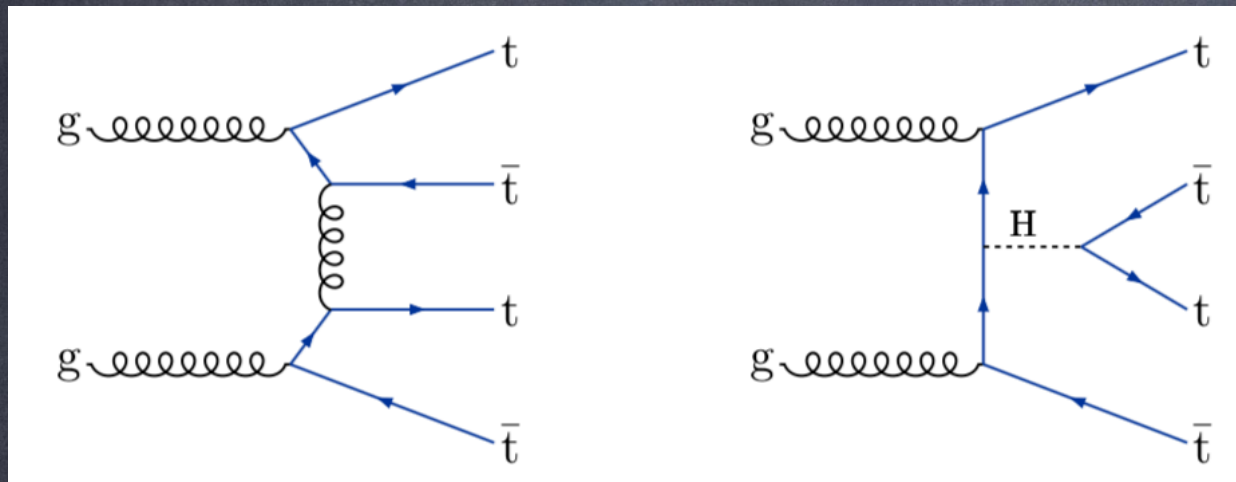- Couplings to the Higgs test the role played by the top in the generation of mass (EWSB)

tthh coupling crucial in composite Higgs models:

it emerges from non-linearities

$$\mathcal{L} \supset -y\frac{m_t}{v}t\bar{t}h - \kappa\frac{1}{3!}\frac{3m_h^2}{v}h^3 - c_t\frac{1}{2!}\frac{m_t}{v^2}t\bar{t}hh$$

Note: gg->hh also received other New Physics contributions!

HL-LHC

$\sqrt{s}$ = 14 TeV

tthh
gg→hh

1905.03772
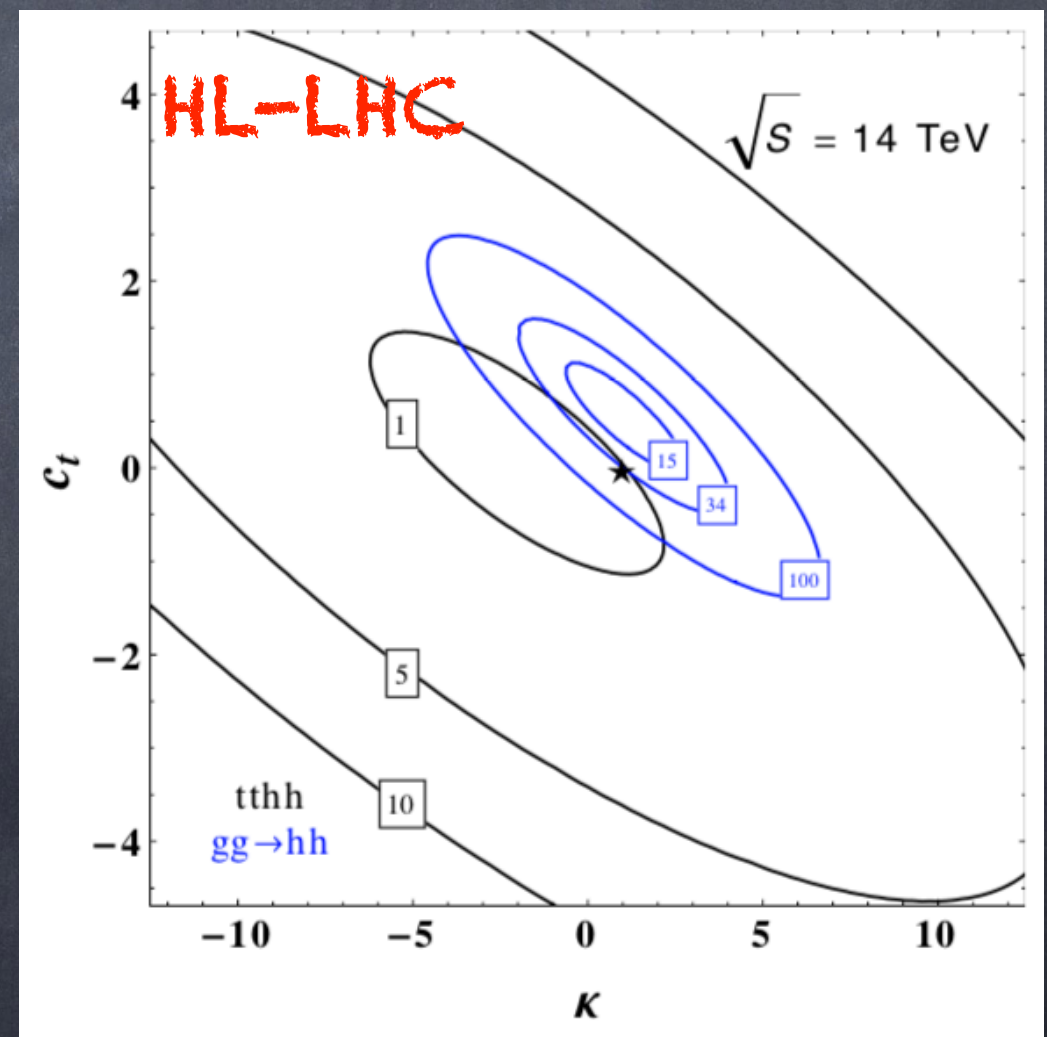
2) Four tops

ATLAS $\quad \mu = 2.0 \pm 0.4(\text{stat})\,^{+0.7}_{-0.4}(\text{syst}) = 2.0\,^{+0.8}_{-0.6}.$

CMS $\quad 12.6^{+5.8}_{-5.2}\text{ fb.}\ /\ 12.0^{+2.2}_{-2.5}\text{ fb}$
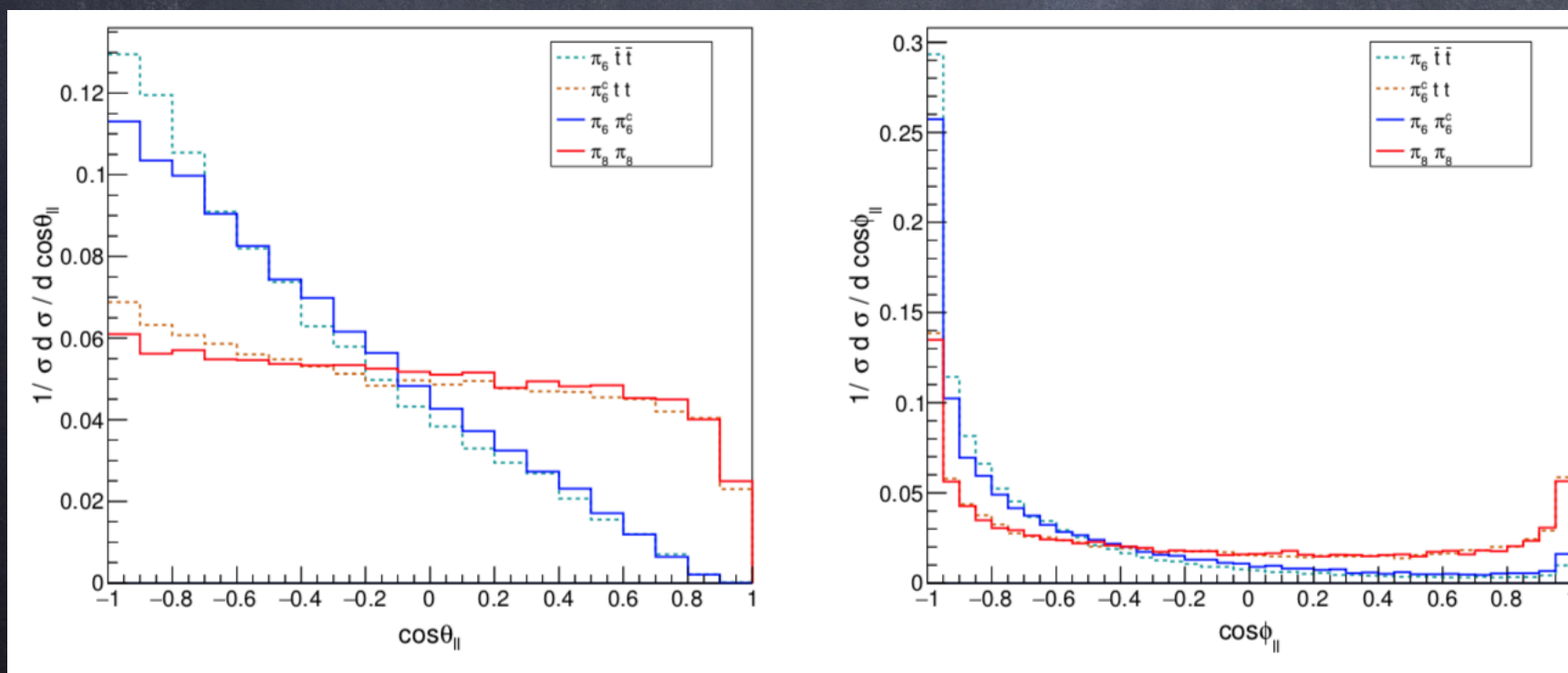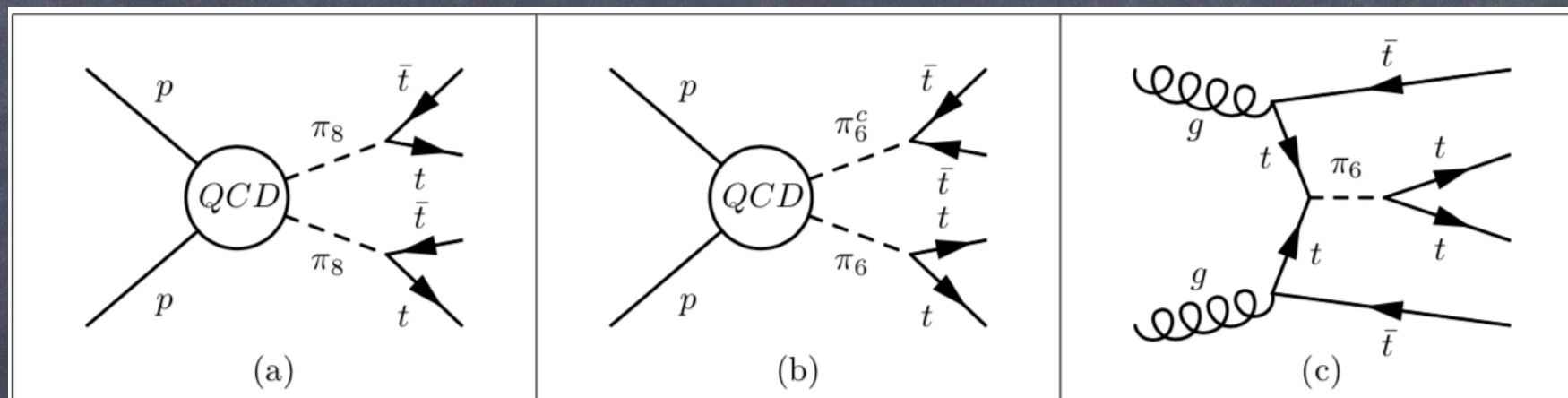
CMS offers some interpretations:

ex: indirect bound on the top Yukawa
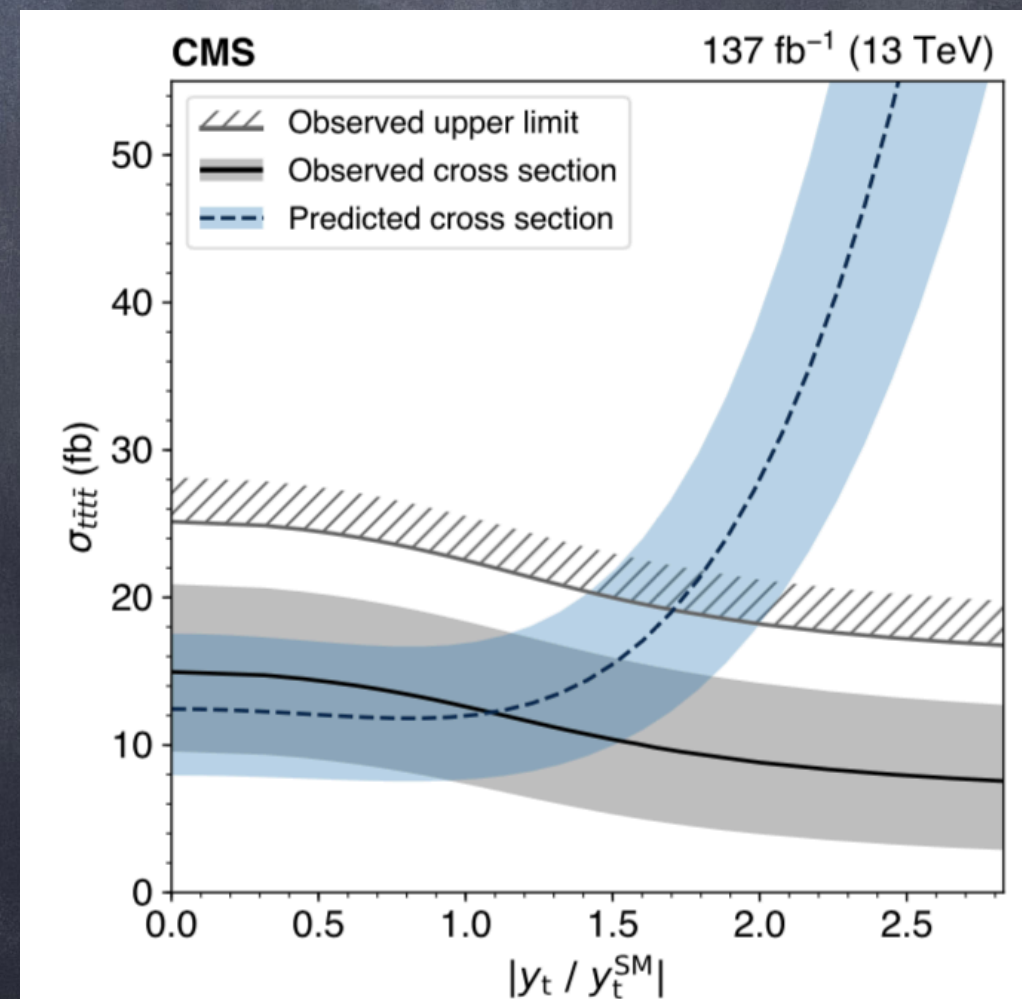
2) Four tops

In composite Higgs models with top partial compositeness scalar octets are ubiquitous (and exotic sextets possible).
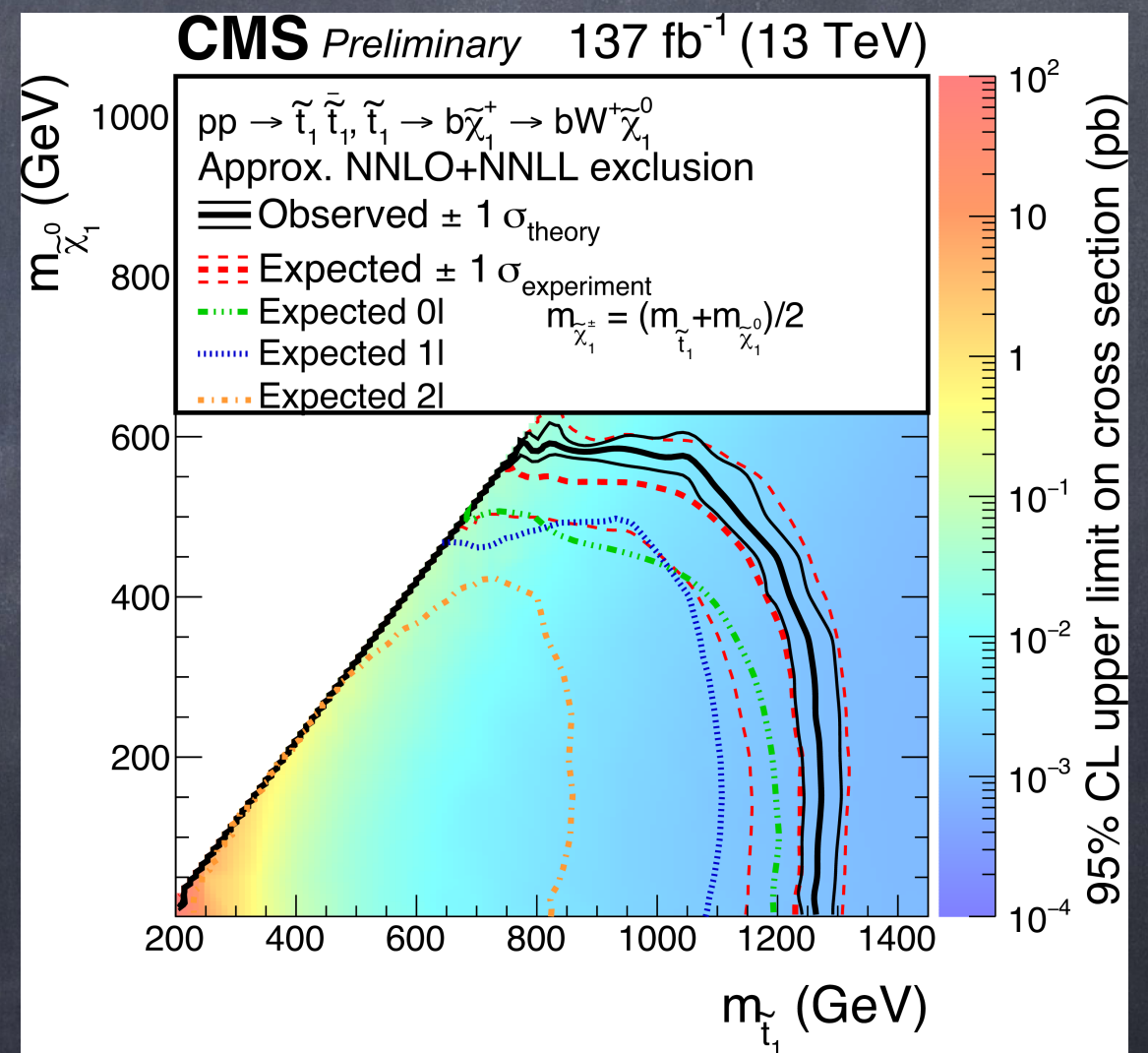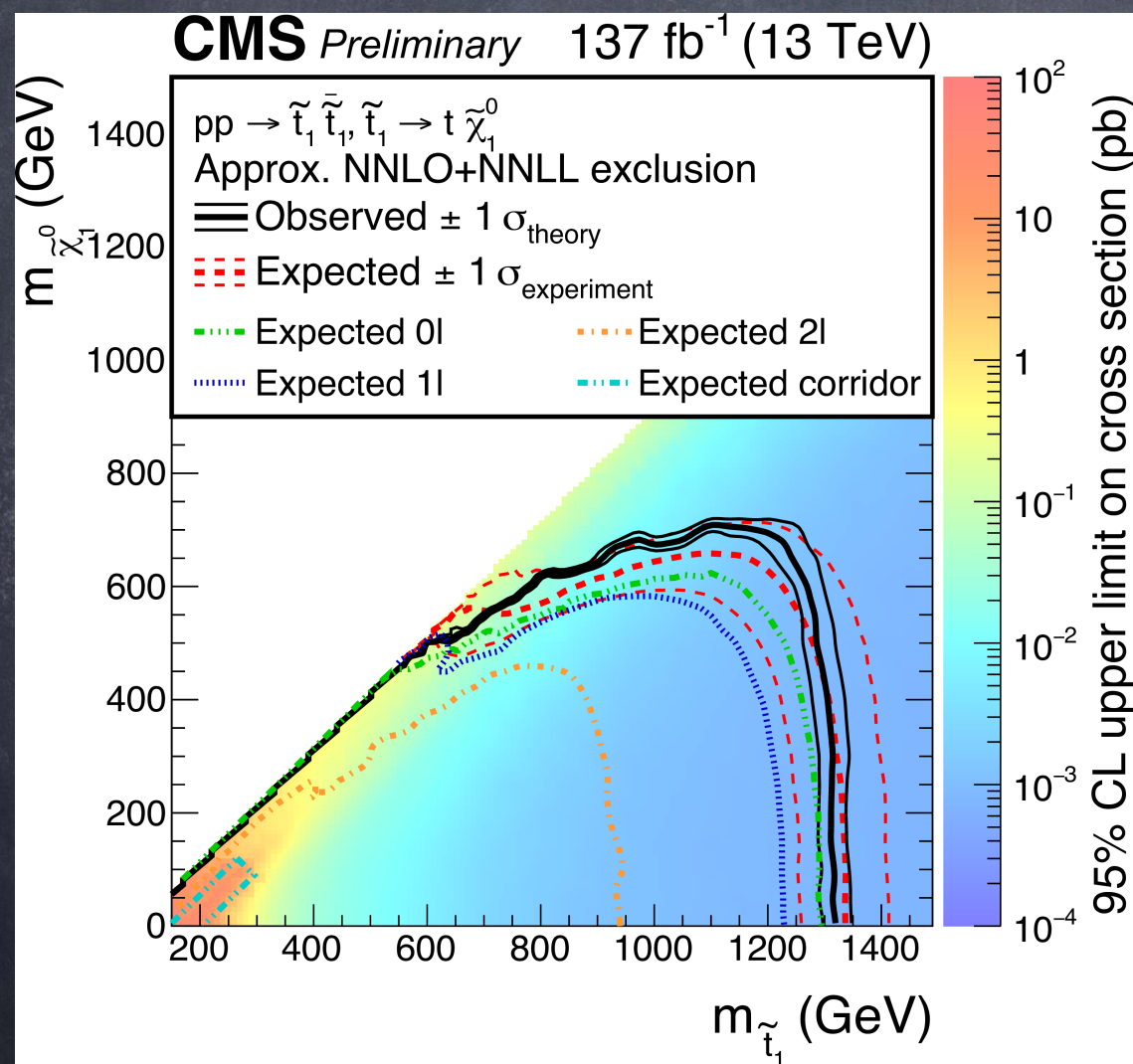
(see 1507.02283)

SSL pair angles can distinguish sextet from octet.

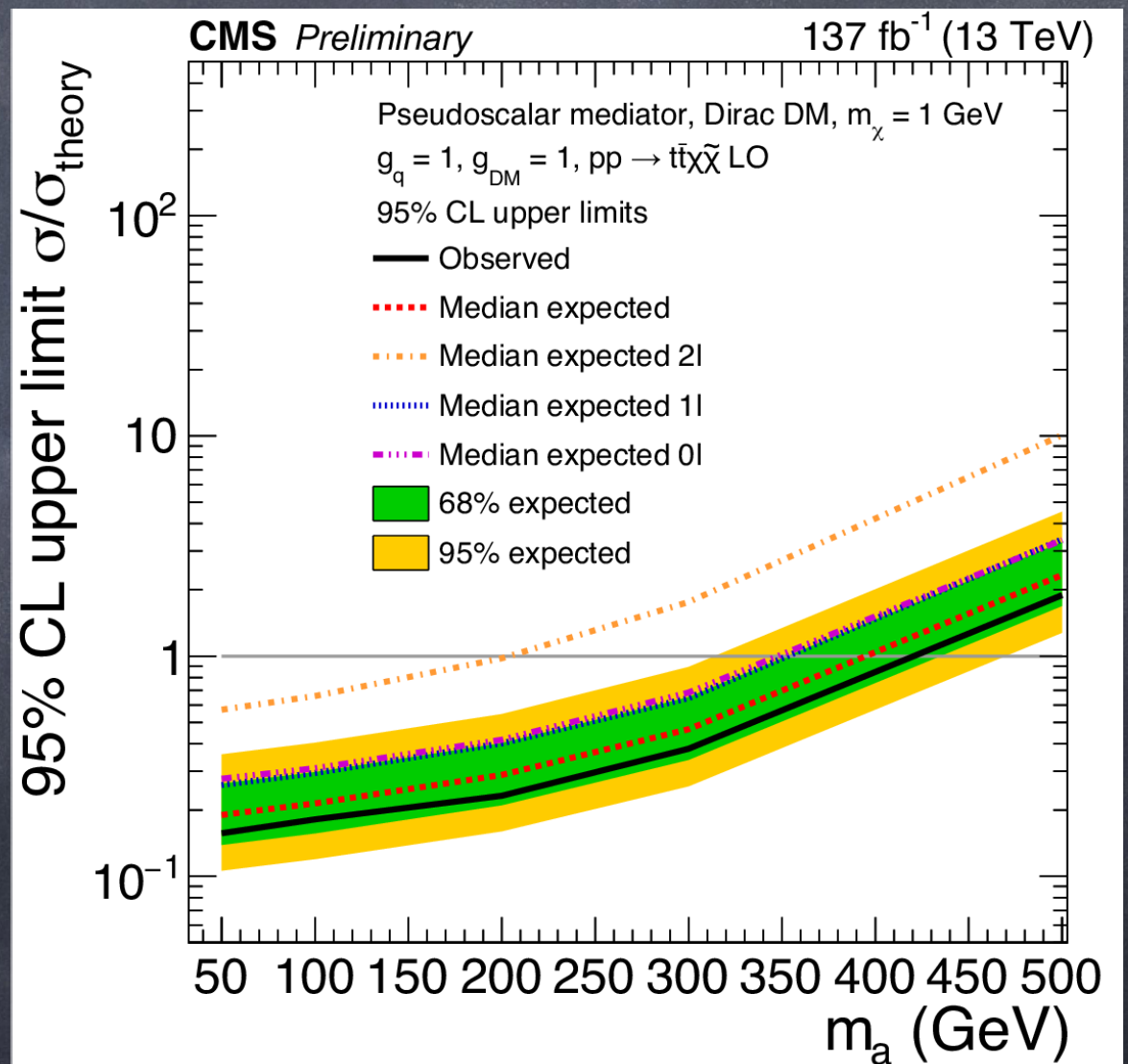# 3) the company of the top?
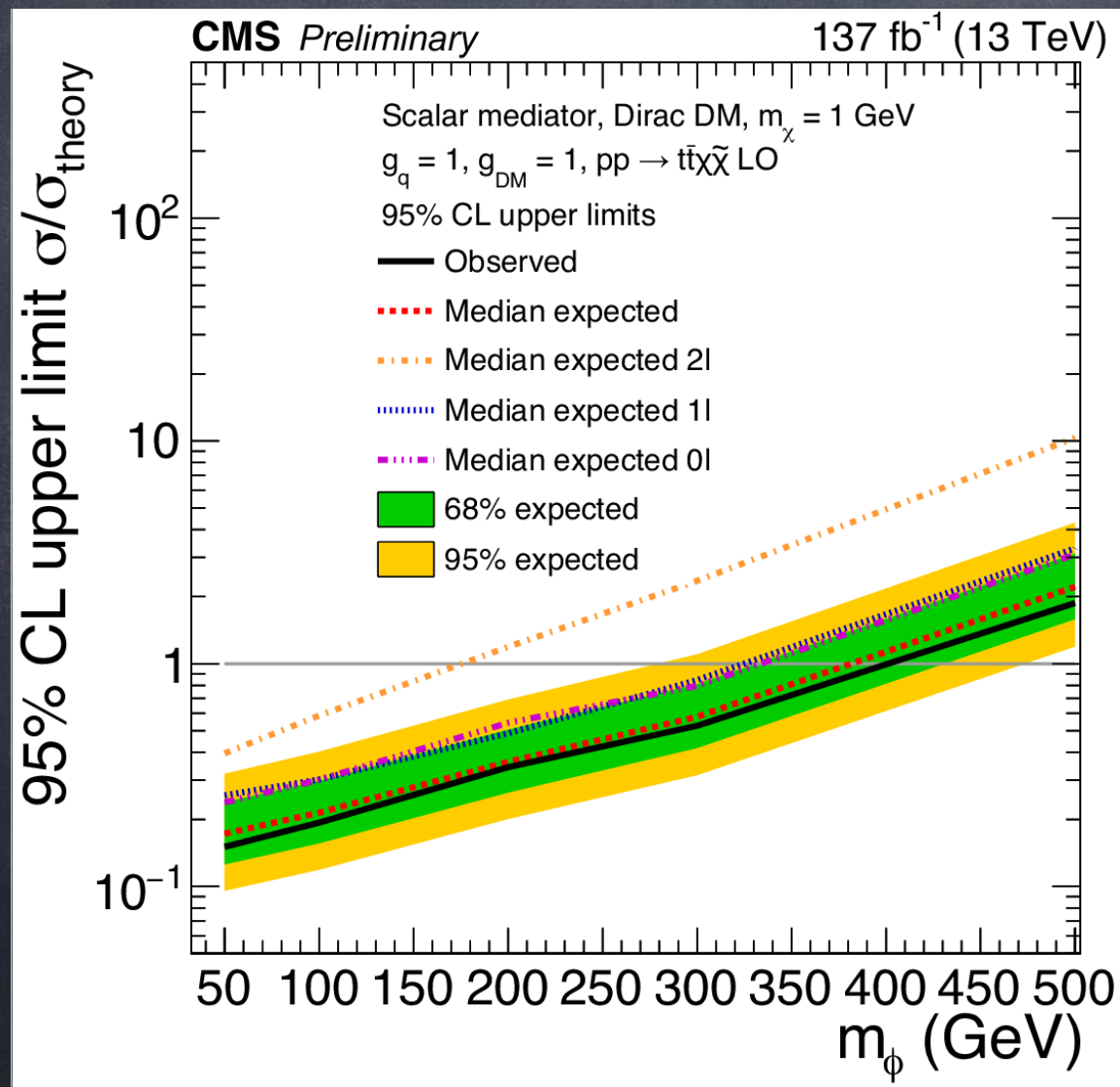
- SUSY stops (and tt + MET) well covered

- With proper rescaling, applies to fermionic partners

see 1607.02050

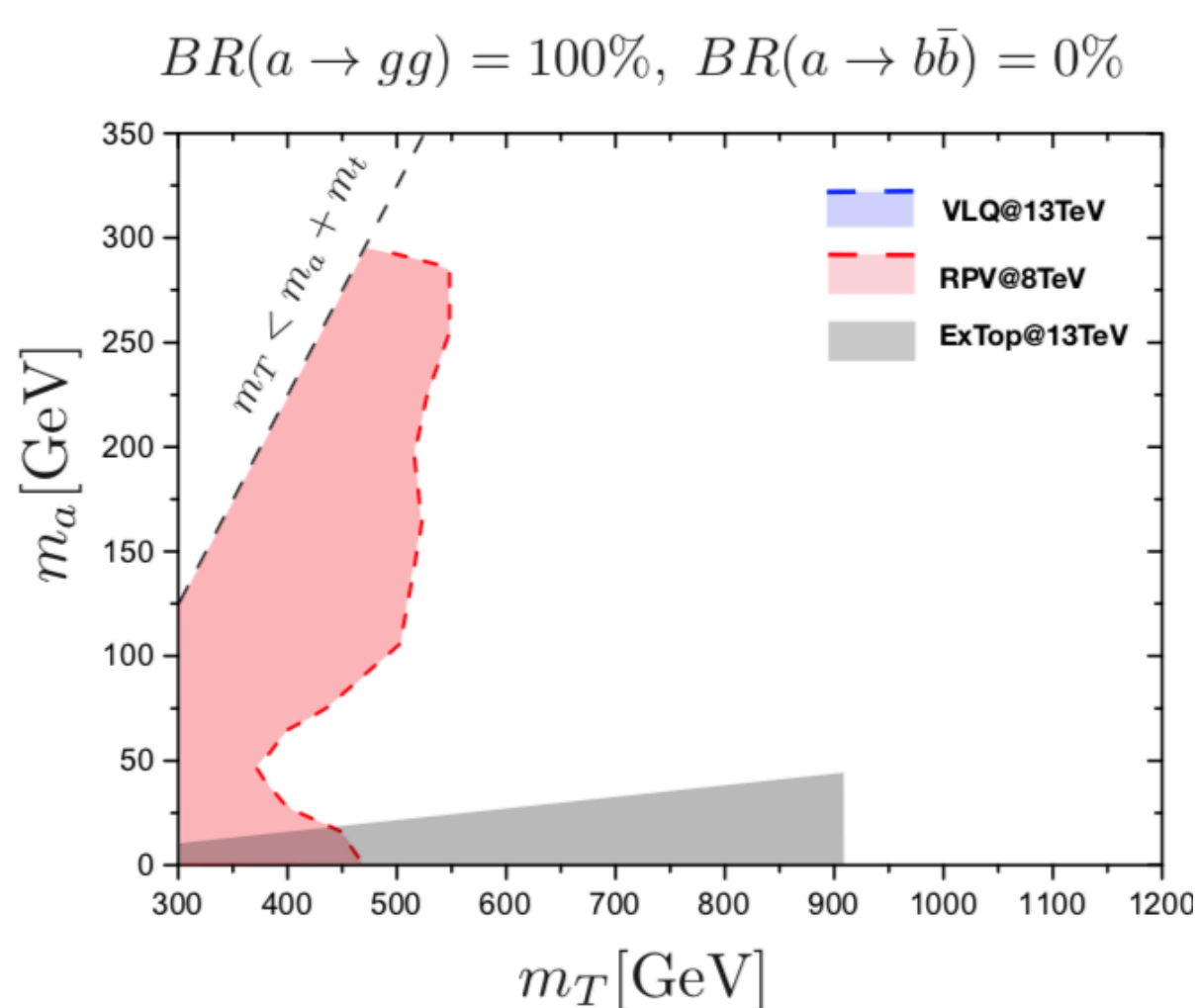# 3) the company of the top?

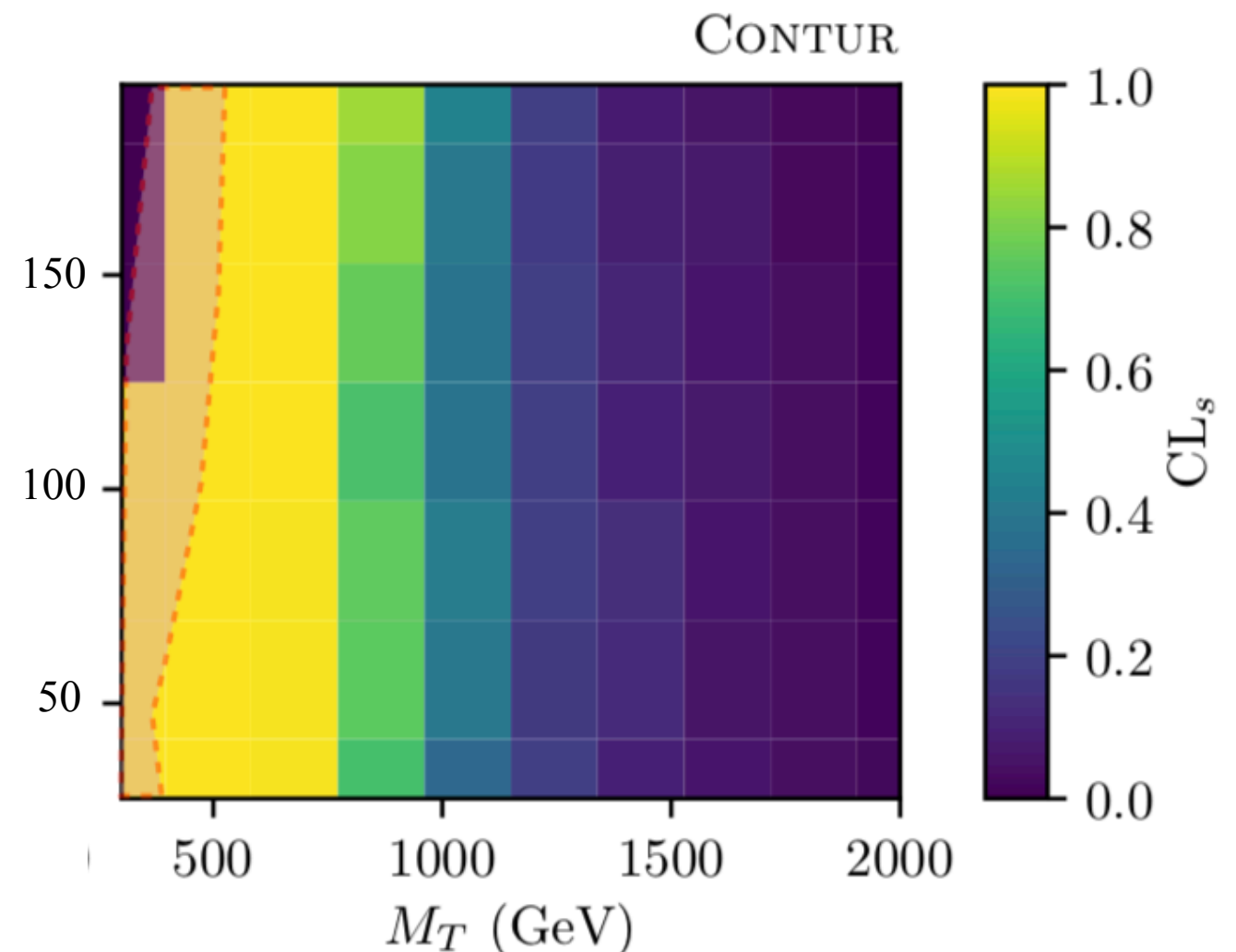- SUSY stops (and tt + MET) well covered

3) the company of the top?

- composite top partners: non-standard decays

see 1803.00021

$$T \to t\, a \quad [a \to gg]$$

$BR(a \to gg) = 100\%, \quad BR(a \to b\bar{b}) = 0\%$

VLQ@13TeV

RPV@8TeV

ExTop@13TeV

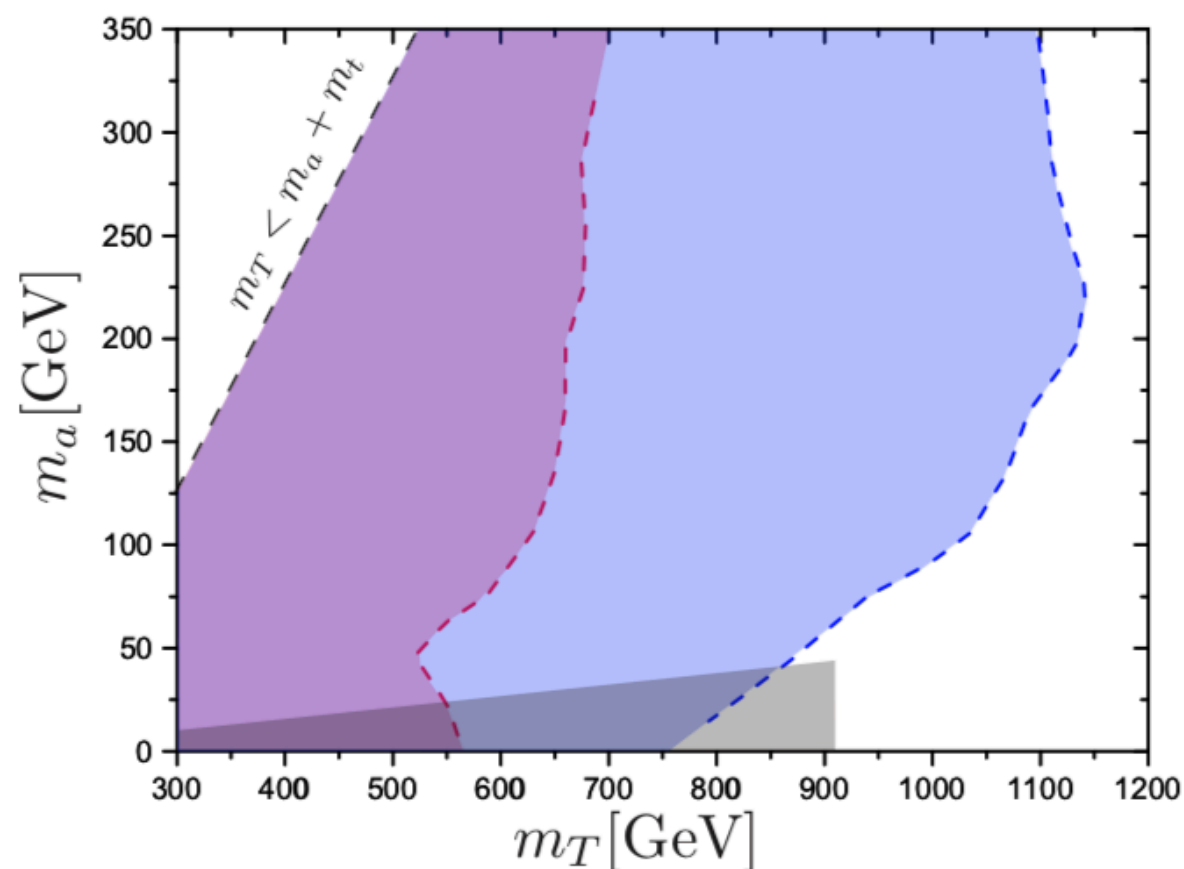$m_T < m_a + m_t$

1908.07524

CONTUR

2002.12220 (Les Houches Proceedings)

3) the company of the top?

- composite top partners: non-standard decays

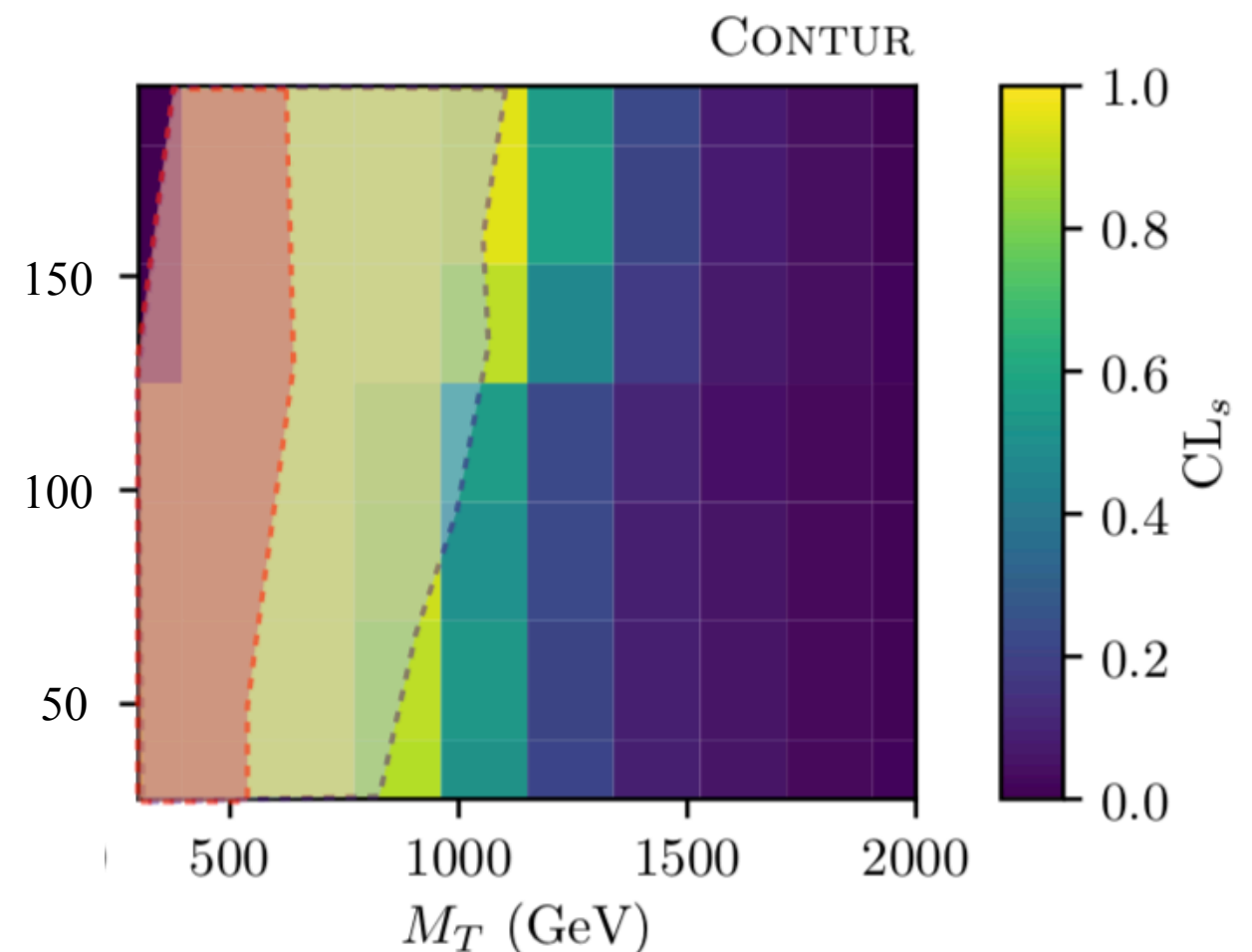see 1803.00021

$$T \to t\, a \quad [a \to bb]$$

$BR(a \to gg) = 0\%, \quad BR(a \to b\bar{b}) = 100\%$

1908.07524

CONTUR

2002.12220 (Les Houches Proceedings)

Top BSM questions
(beyond EFT)

- Top decays to non-SM light states.

- Can SM cross sections constrain top partners? tt+XX...

- Multi-top production interpretations: are we being complete and inclusive?

- Any connection between top and lepton universality violation? (RK)