Model Agnostic limits on Colored Top Partners

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Arxiv:1606 (±1) .xxxx

with Rouven Essig, Patrick Meade and Yiming Zhong

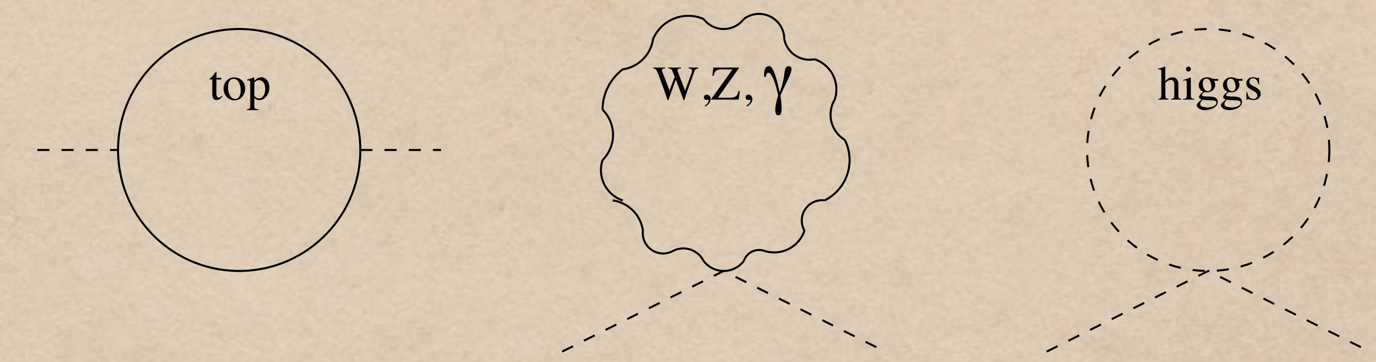
Talk Outline

- The Hierarchy Problem and colored top partners
- Effects on Higgs Precision Measurements
- Ways to Hide
- Results

The Hierarchy Problem

- Electroweak scale unnatural
- Require symmetries to protect a light Higgs mass
- Dire need for new physics

How Dire?



top loop	$-\frac{3}{8\pi^2}\lambda_t^2\Lambda^2$
$SU(2)$ gauge boson loops	$\frac{9}{64\pi^2}g^2\Lambda^2$
Higgs loop	$\frac{1}{16\pi^2}\lambda^2\Lambda^2$

$\Lambda_{top} \lesssim 2$ TeV $\quad \Lambda_{gauge} \lesssim 5$ TeV $\quad \Lambda_{Higgs} \lesssim 10$ TeV.

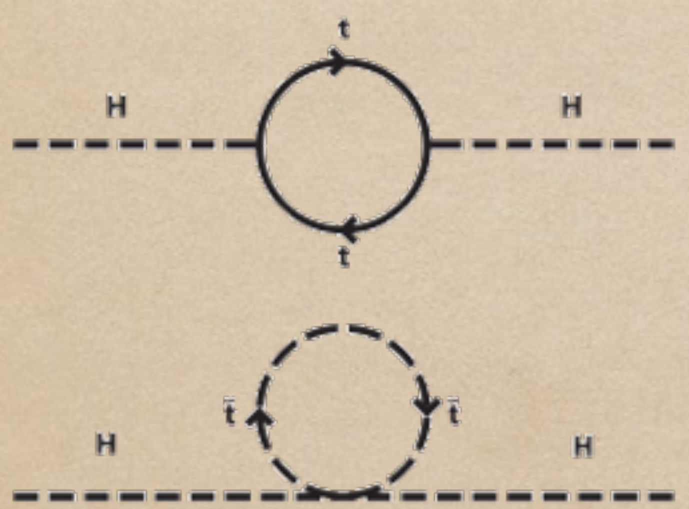
Figures and numbers borrowed from Schmaltz and Tucker-Smith

Solutions

Colored Top Partners

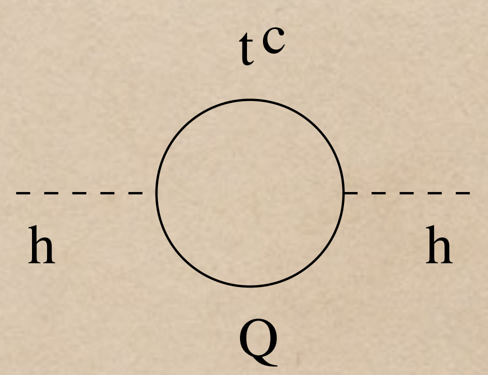
- Supersymmetry => $\lambda_S = |\lambda_f|$^2

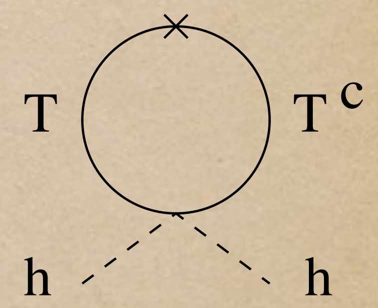
$$V_{CW} \supset \sum_i (-1)^F \frac{1}{32\pi^2} M_i^2 \Lambda^2$$



- Fermionic Top Partners
- Higgs is a PNGB
- In terms of Higgs couplings

$$M_T \lambda_T = f \lambda_t^2$$





Where are the colored TPs?

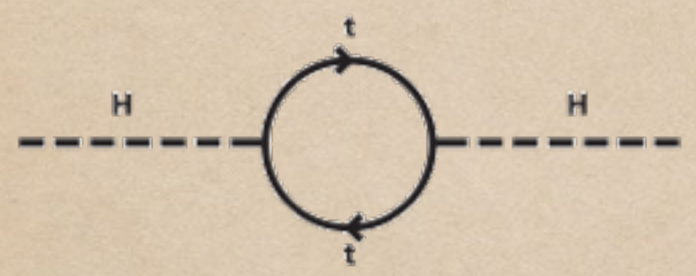
- Higher Mass of top partners => a more finely tuned theory(BAD)
- LEP+Tevatron+Run 1 see no stops/heavy tops (BAD)

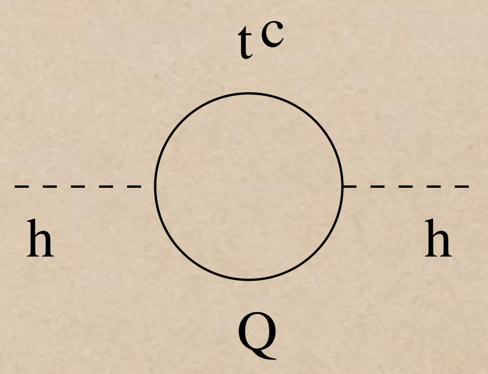
Ways to test colored TP

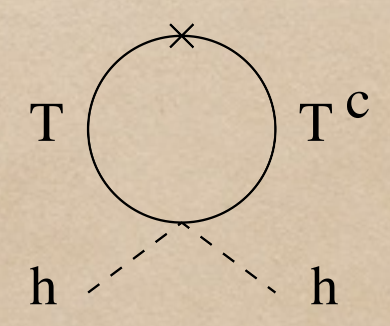
- Copiously produced at the LHC
- Direct detection: decay to SM colored and LSP
- DD Caveats: Stealth SUSY, Oddest Little Higgs

  arXiv:1105.5135:Fan,Reece,Ruderman arXiv:1506.05130 :Anandakrishnan et al.
- Same topologies definitely contribute to ggF and diphoton decay
- affect Higgs precision measurements.

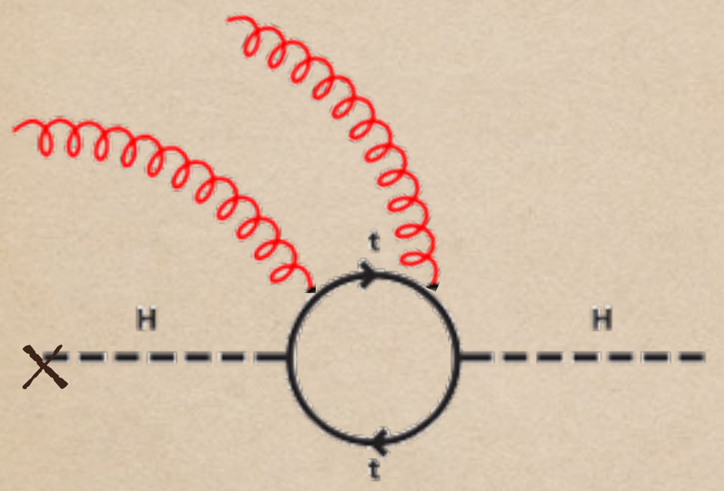
ggF

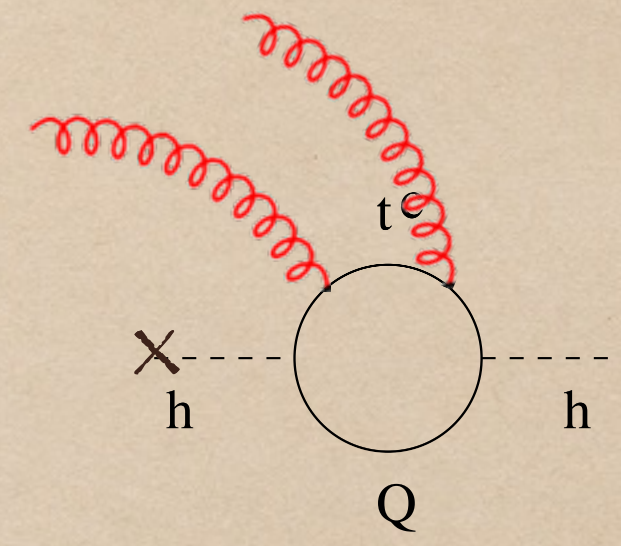


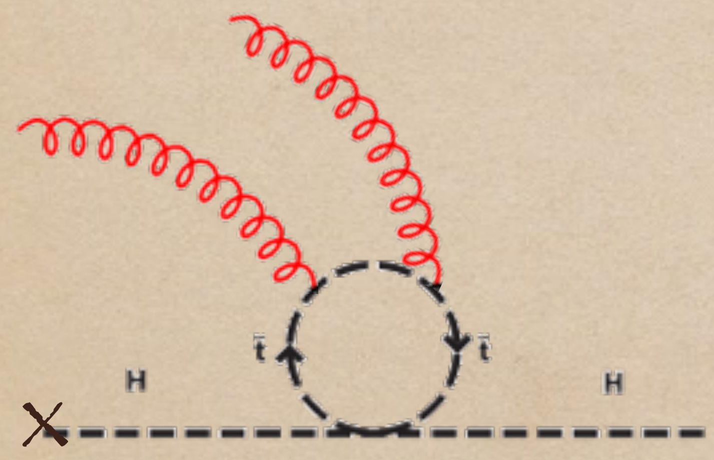


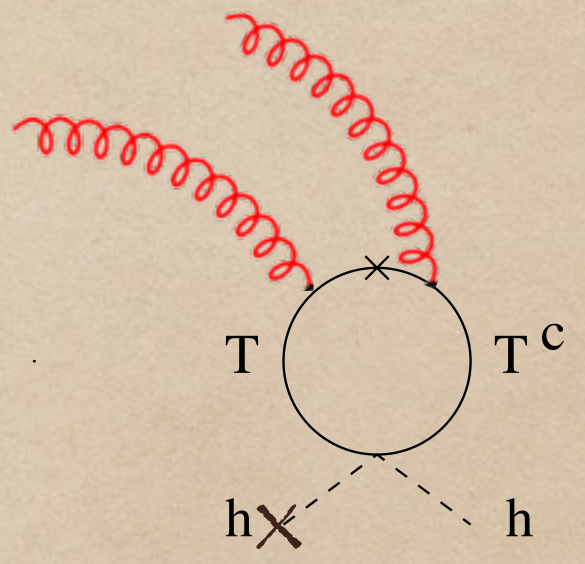


ggF









Is it possible to kill the possibility of colored top partners ameliorating the hierarchy problem just from this property?

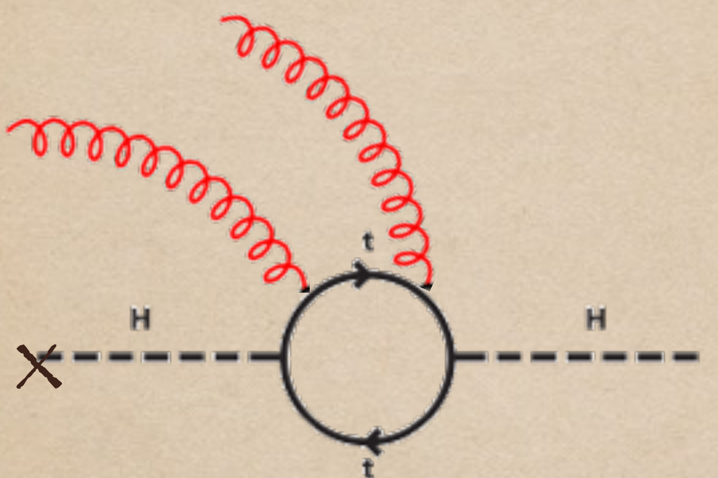
Or can we hide them by messing with other standard model yukawas?

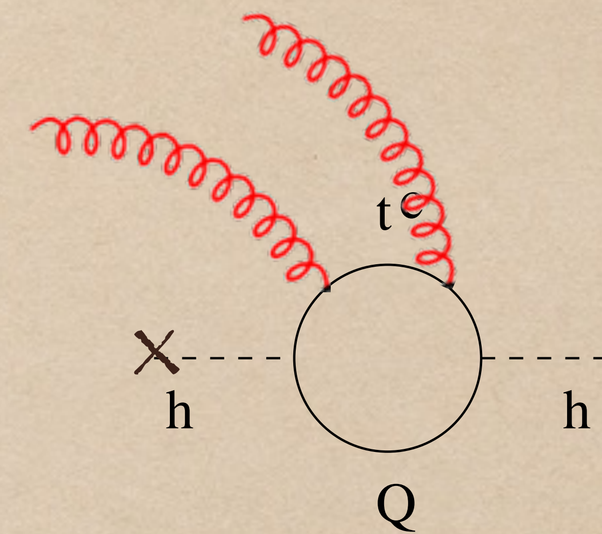
Higgs Precision

- Production
- ggF
- VBF
- WH
- ZH
- tth

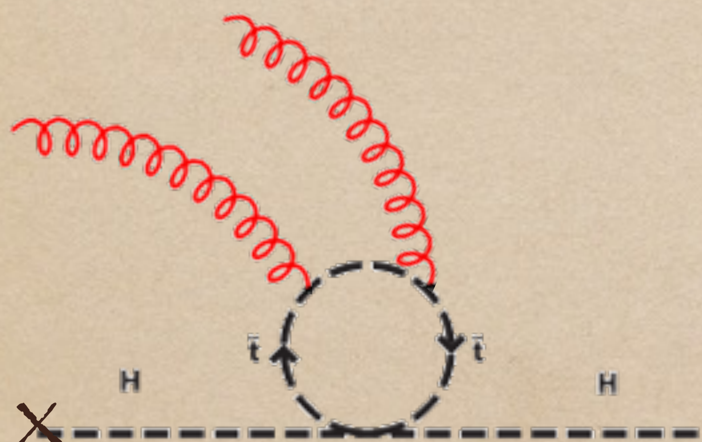
- Decay
- AA
- WW,ZZ
- bb
- gg
- invisible

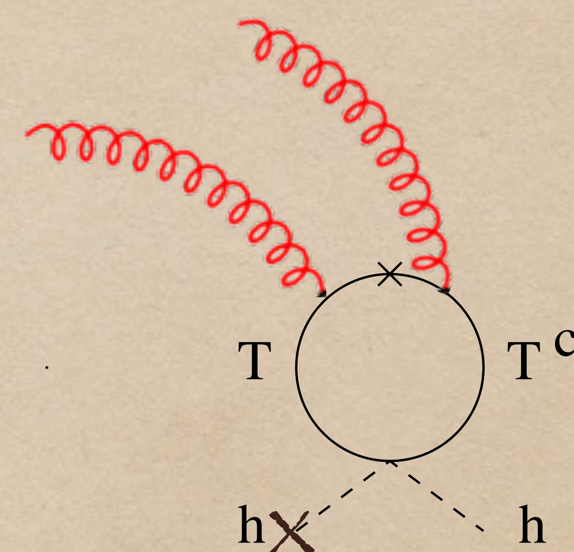
Signal strength Modifiers





rt





rtG

$rf=\mu_f/\mu_{fSM}$

Higgs Precision

- Production
- ggF
- VBF
- WH
- ZH
- tth

- Decay
- AA
- WW,ZZ
- bb
- gg
- invisible

Higgs Precision

- Production
- ggF rt(1+rtG)
- VBF
- WH
- ZH
- tth rt

- Decay
- AA rV+rX-0.28rt(1+rtG)
- WW,ZZ
- bb
- gg rt(1+rtG)
- invisible

Higgs Precision

- Production
- ggF rt(1+rtG)
- VBF rV
- WH rV
- ZH rV
- tth rt

- Decay
- AA rV+rX-0.28rt(1+rtG)
- WW,ZZ rV
- bb rb
- gg rt(1+rtG)
- invisible rinv

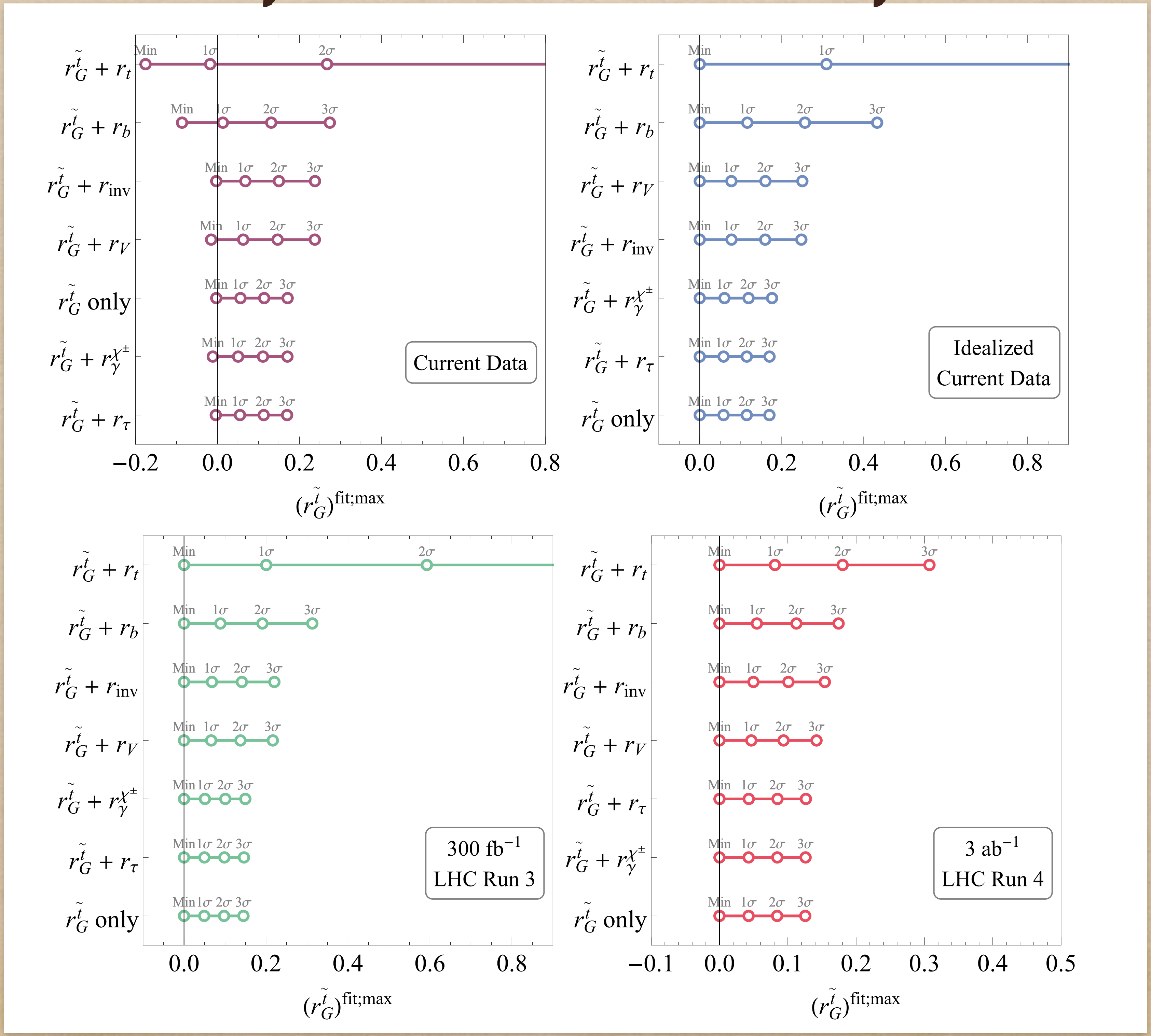
Data

- Full Run 1
- Run II updated to Moriond
- Future colliders

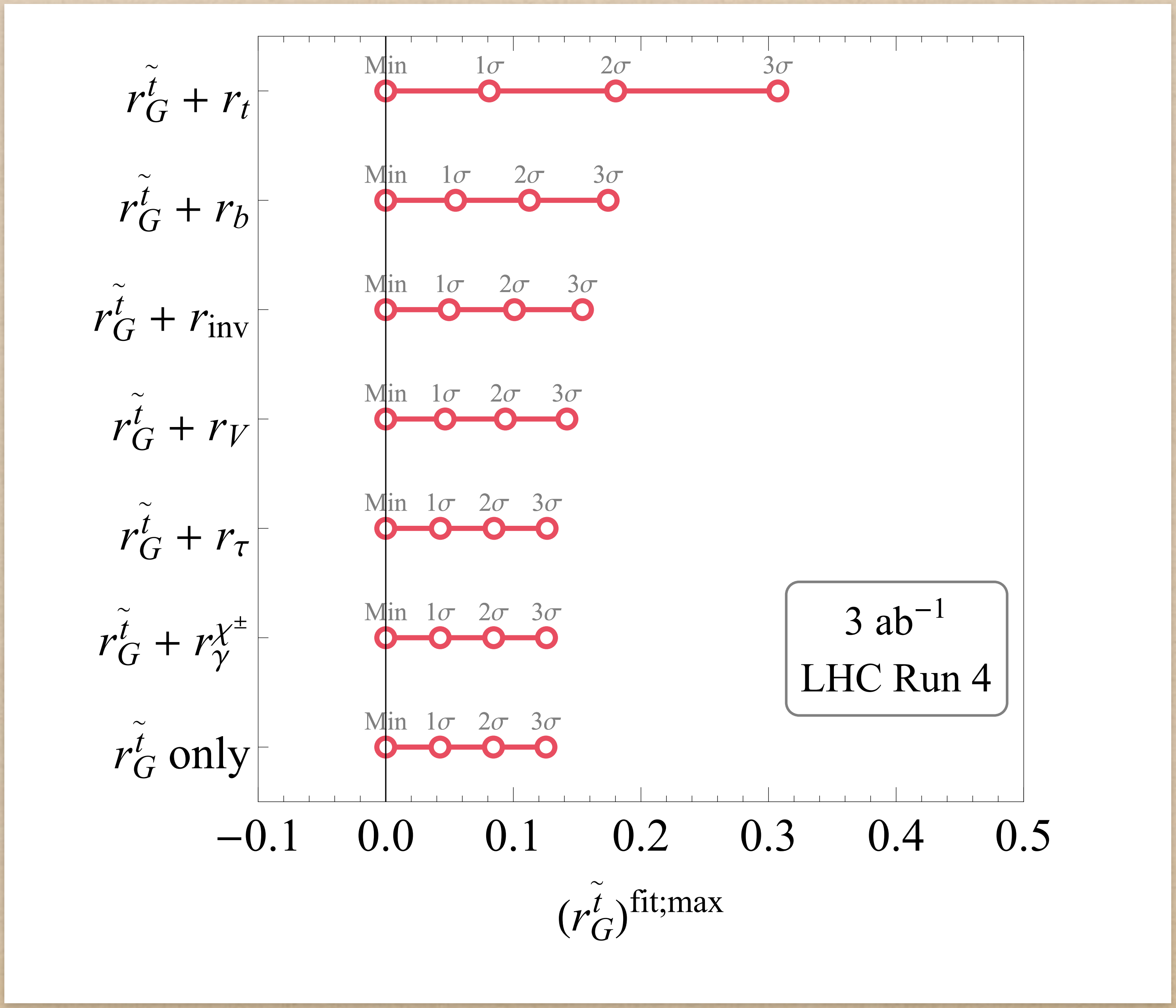
SUSY

- Model agnostic conversion of rtG limits to stop masses Refer Arxiv:1401.7671 Jiji Fan, Matt Reece
- Constrained rtG => smaller stop masses disallowed=>Tuned theory

Scalar:parameter potency



Scalar:parameter potency



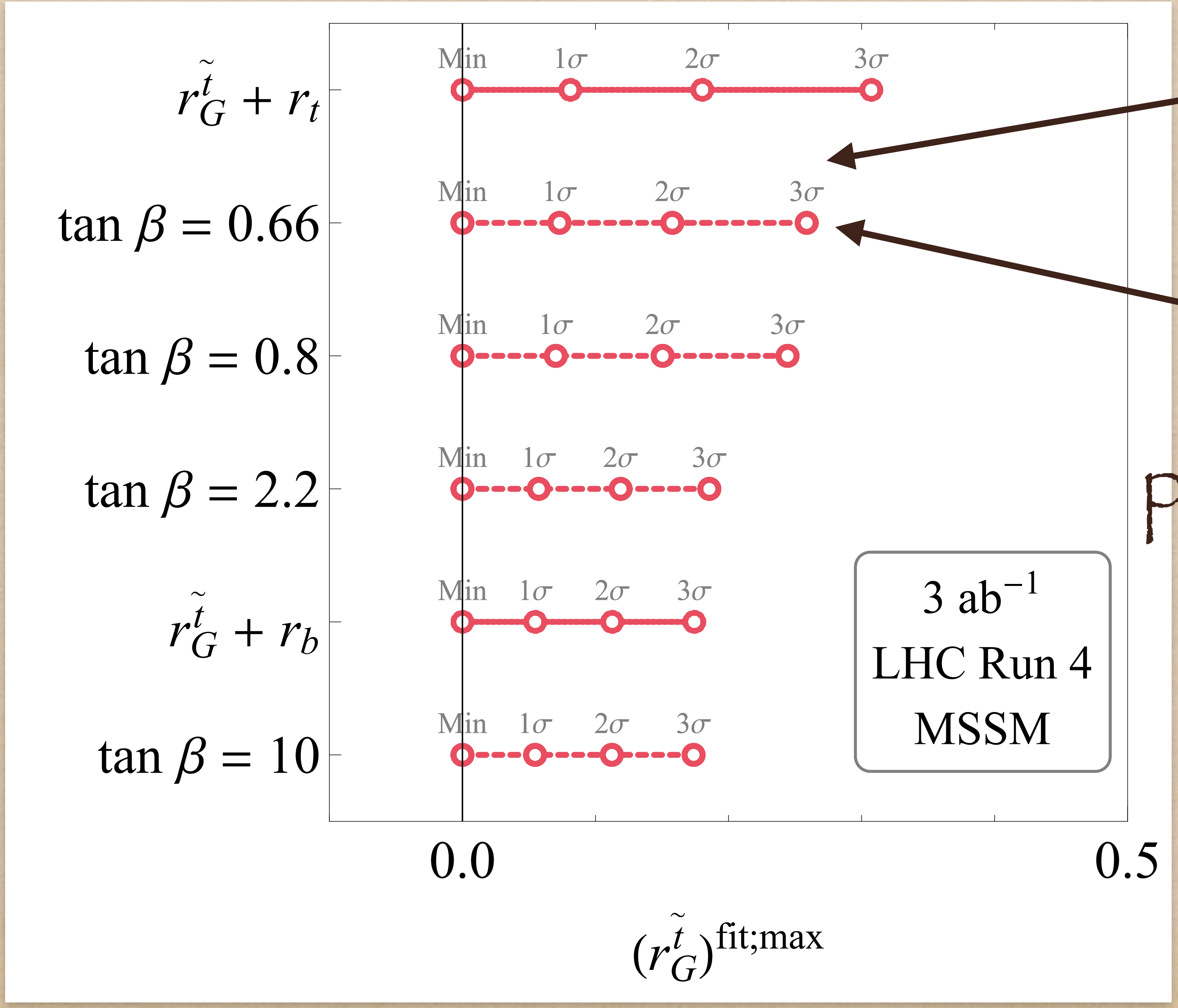
CONCRETE REALIZATION

Extending the Higgs Sector

- 2HDM (refer to comprehensive Plenary talk by Carlos Wagner)
- Type-2 used in the MSSM
- Hu and Hd mix and share Higgs vev=246

$$r_t = \sqrt{1 - \frac{r_b^2 - 1}{\tan^2\beta}}, \quad r_V = \frac{\tan\beta}{1+\tan^2\beta}\left(\frac{r_b}{\tan\beta} + \sqrt{1+\tan^2\beta - r_b^2}\right).$$

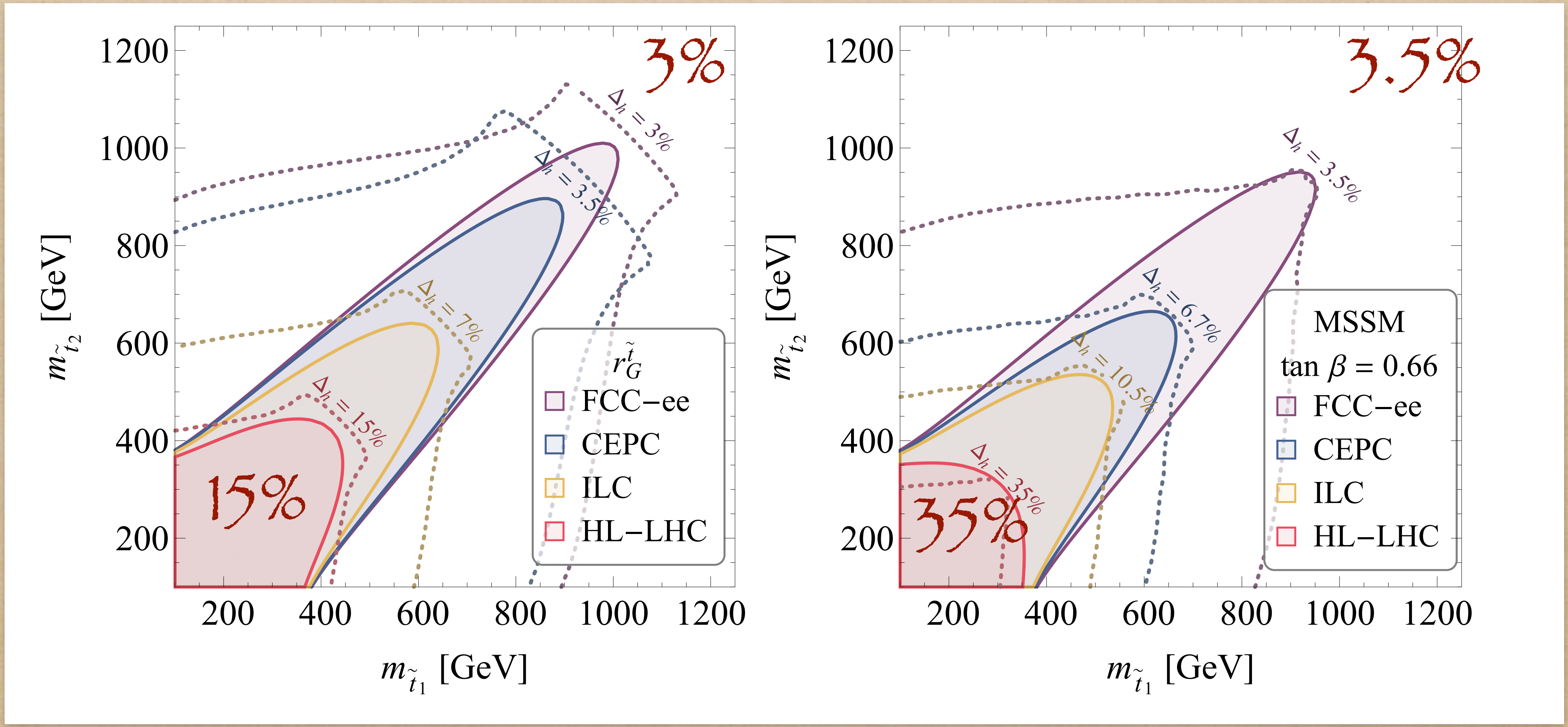
Scalar:Concrete realization



4HDM

farewell perturbativity

Tuning



3%
3.5%
15%
35%
Δ_h = 3%
Δ_h = 3.5%
Δ_h = 7%
Δ_h = 15%
Δ_h = 6.7%
Δ_h = 10.5%
Δ_h = 35%
$r_G^{\tilde{t}}$
MSSM
tan β = 0.66
FCC−ee
CEPC
ILC
HL−LHC
$m_{\tilde{t}_1}$ [GeV]
$m_{\tilde{t}_2}$ [GeV]

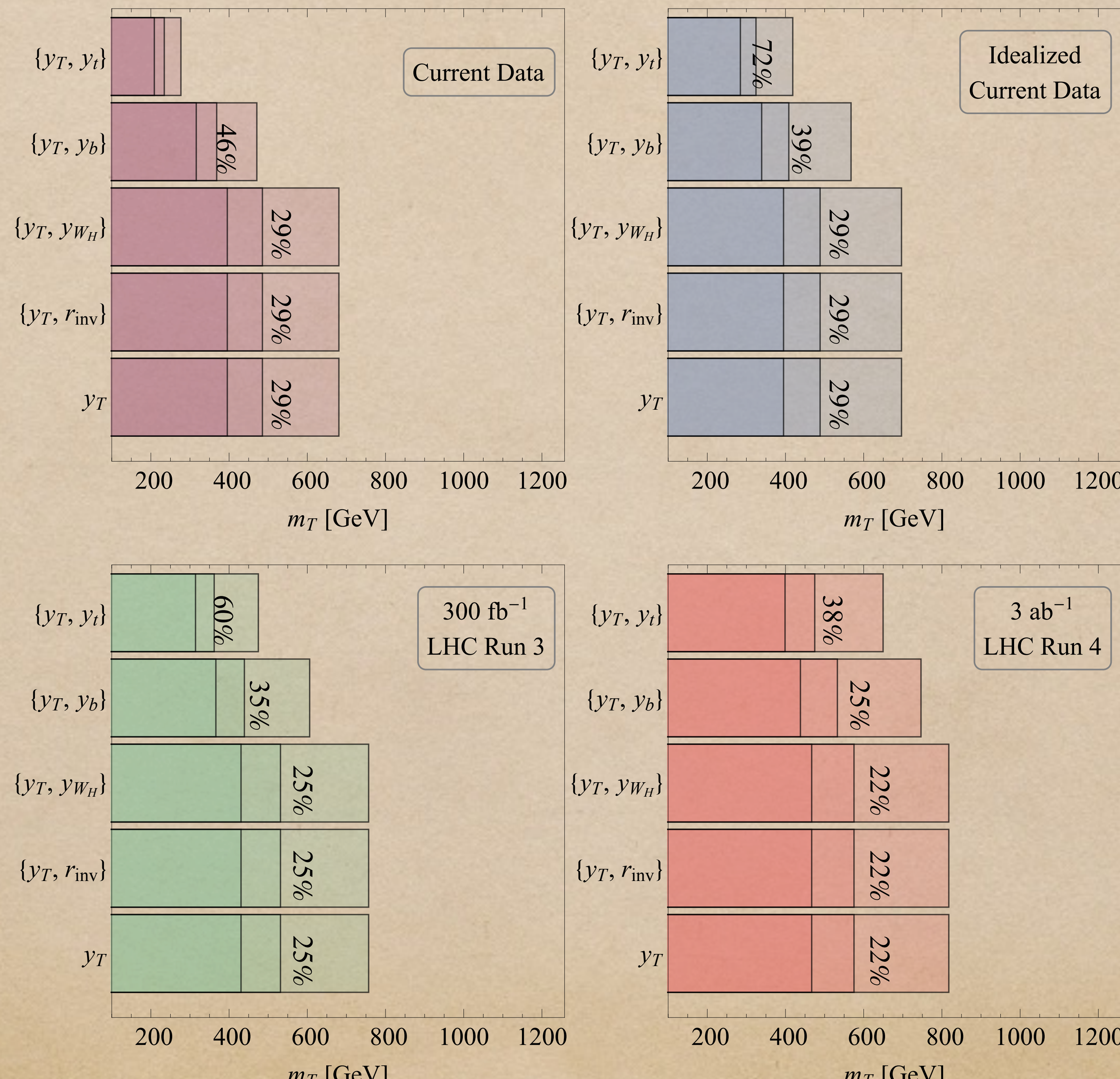
Fermions

- Assume a singlet fermion with non-renormalizable coupling to the Higgs
- (mT-a h^2) TTc
- Cancellation condition => yT=-(mt^2)/(mT^2)

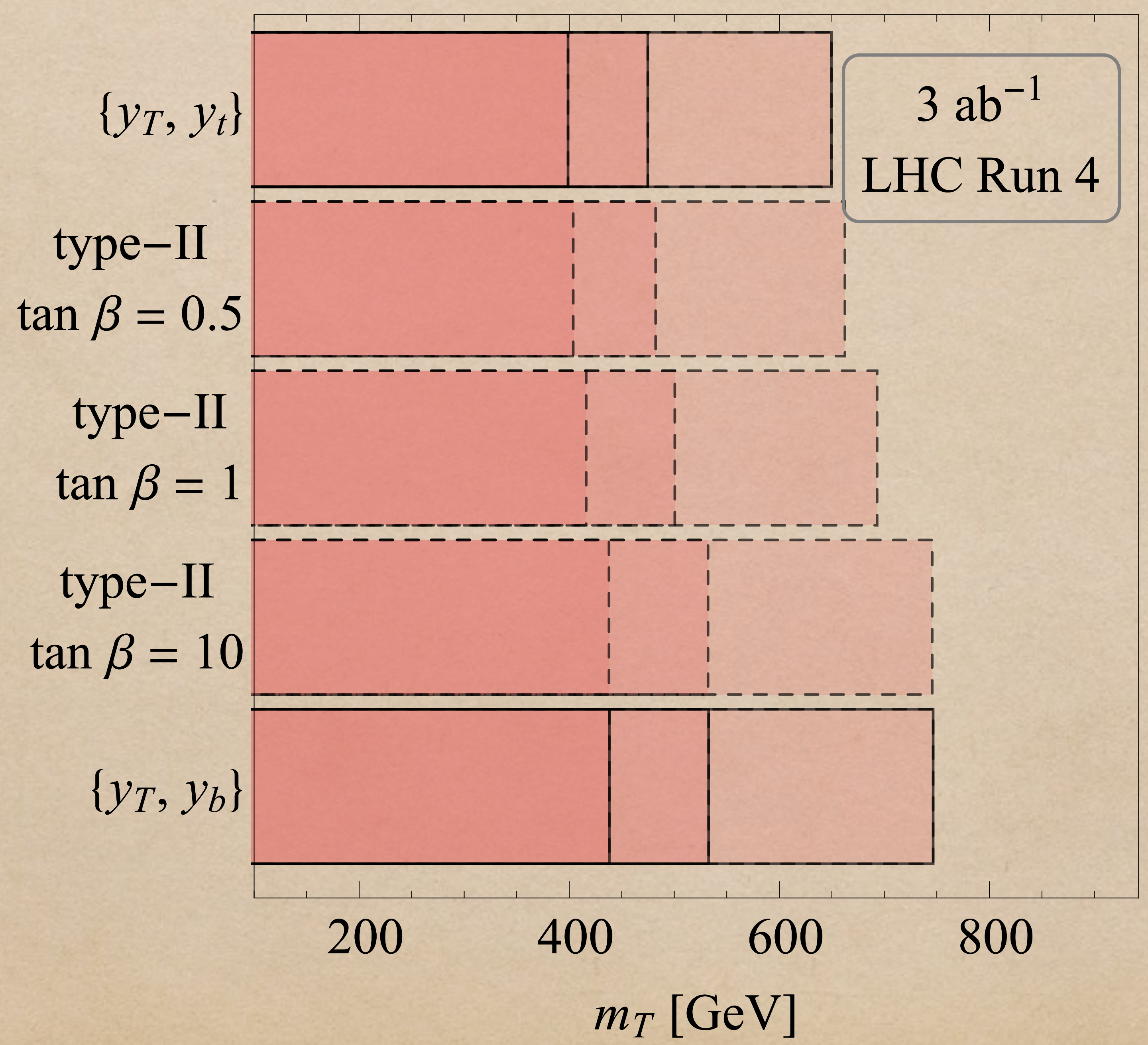
Refer Arxiv:arXiv:1205.0013 Berger,Hubitz,Perelstein

- We find even in the most general case with off-diagonal mixing, this elegant relation still holds.
- rtG=yT a negative definite quantity for Little Higgs theories

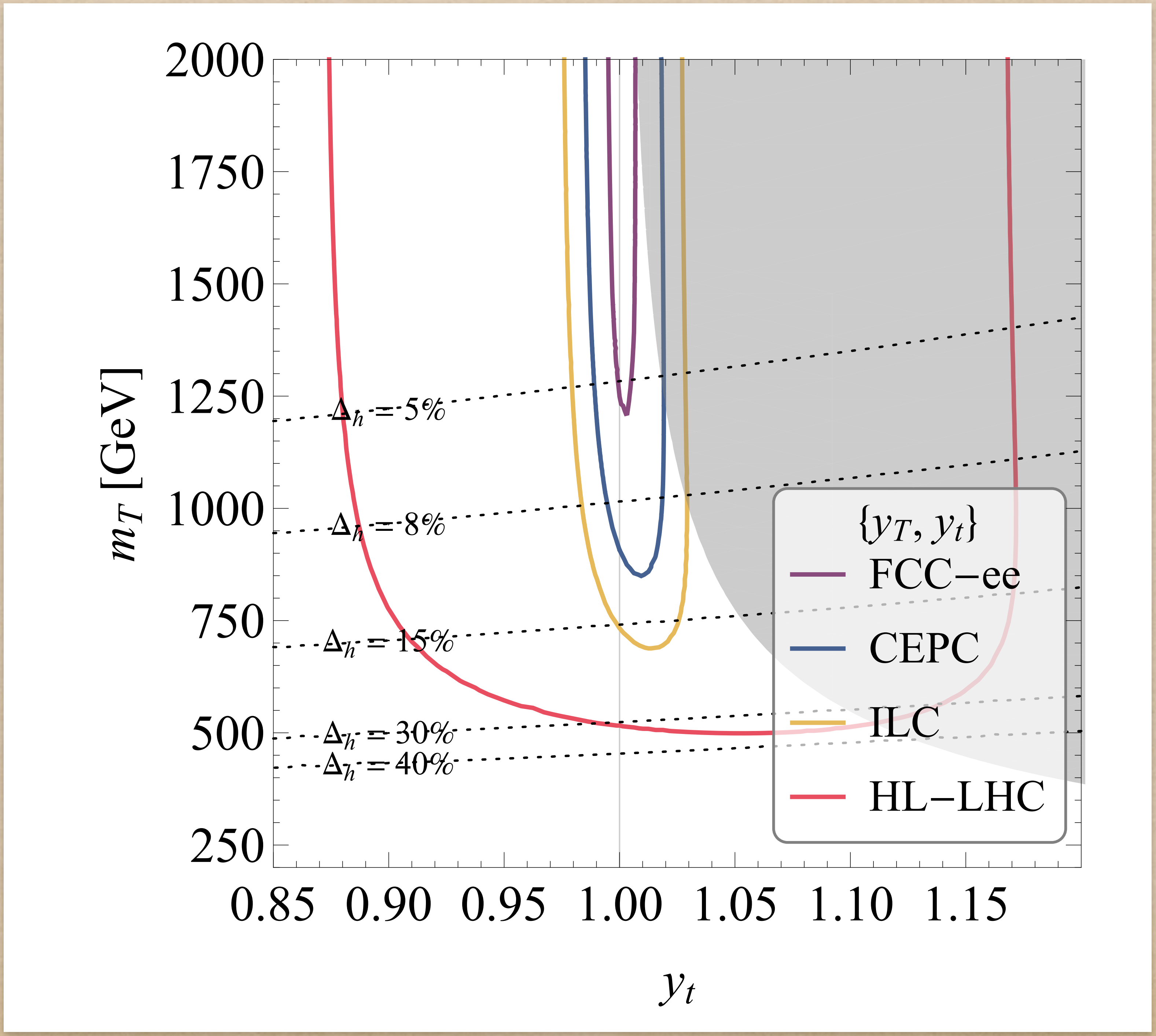
Hiding Potency



Fermion:Concrete Realization

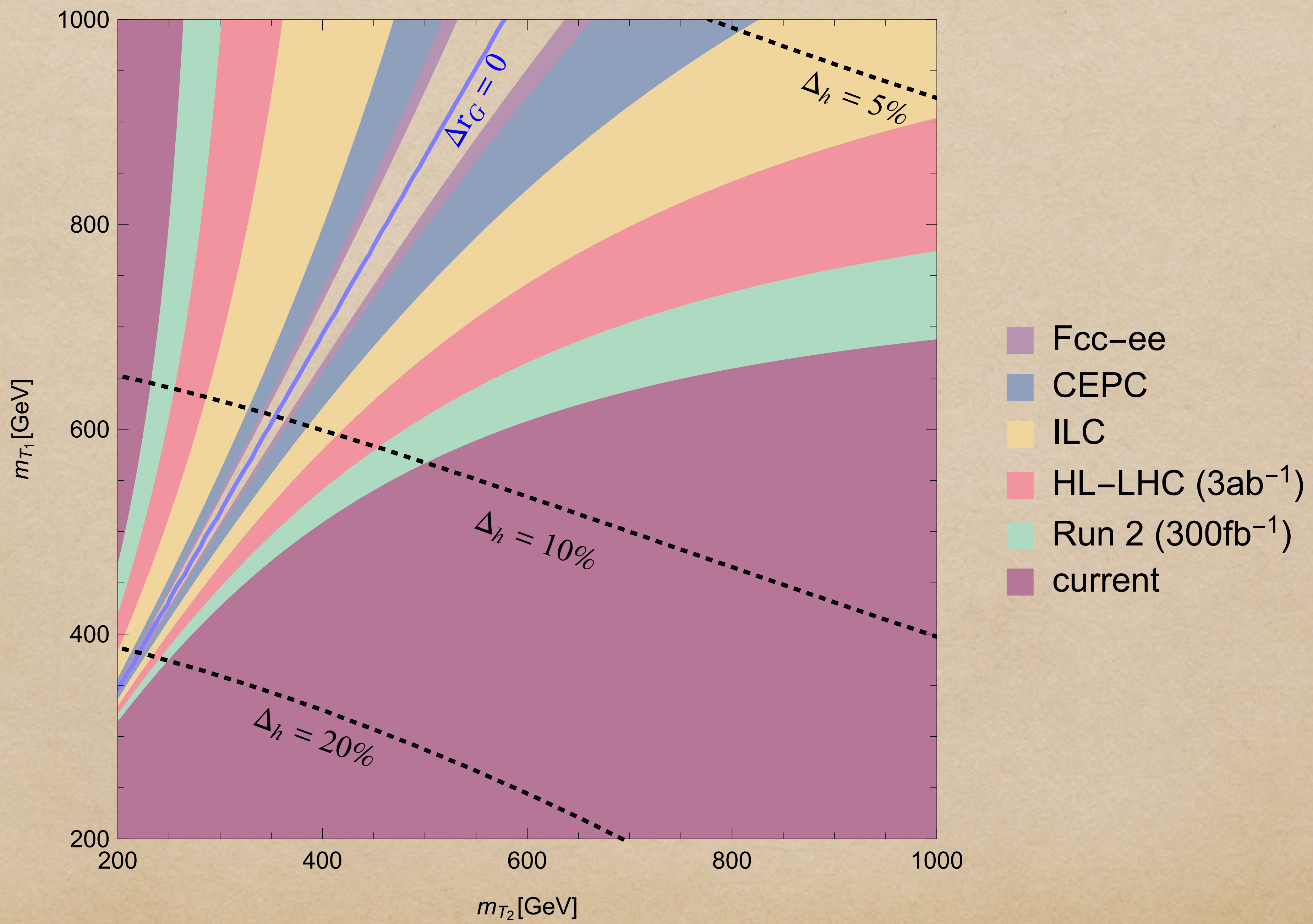


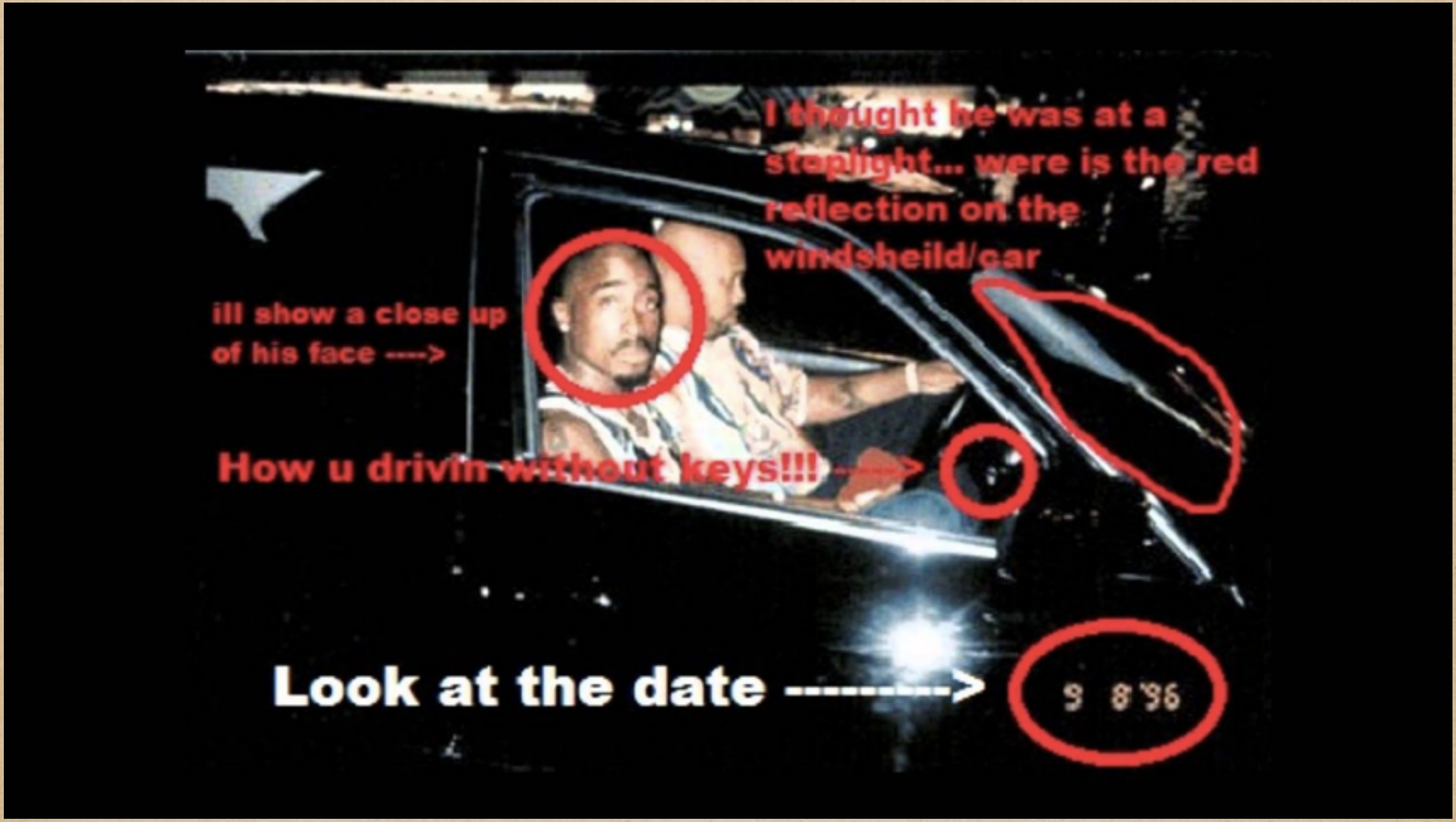
Future Colliders



- Vanilla SUSY => fixes #stops
- Global symmetry like Little Higgs theories => more top partners allowed.
- Extend with 1 more top partner

Two Fermionic top partners




I thought he was at a stoplight... were is the red reflection on the windsheild/car
ill show a close up of his face ---->
How u drivin without keys!!! ---->
Look at the date ----------->
9 8 96

Summary

- Colored top partners hurtling towards demise
- Alternatives exist:

A. Neutral Naturalness

B. Relaxions, N-Naturalness

What is dead may never die