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Constraining Baryogenesis in the Standard Model EFT with dim 6 terms using LHC Higgs physics and EDMs

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Motivation I - Cosmic Frontier

- Observation of asymmetry of matter-antimatter in the Universe.

$$Y_B^{\rm obs} = (8.59 \pm 0.08) \times 10^{-11}$$

Planck

- *How to make a matter filled Universe?*
    - *Baryon number violation*
    - *Departure from thermal equilibrium*
    - *C and CP violation*

Sakharov '67

Motivation II – Intensity Frontier

- High precision, low energy experiments that have strong bounds.
- New CP violating terms have implications in other types of observables such as electric dipole moments.

- ACME bound

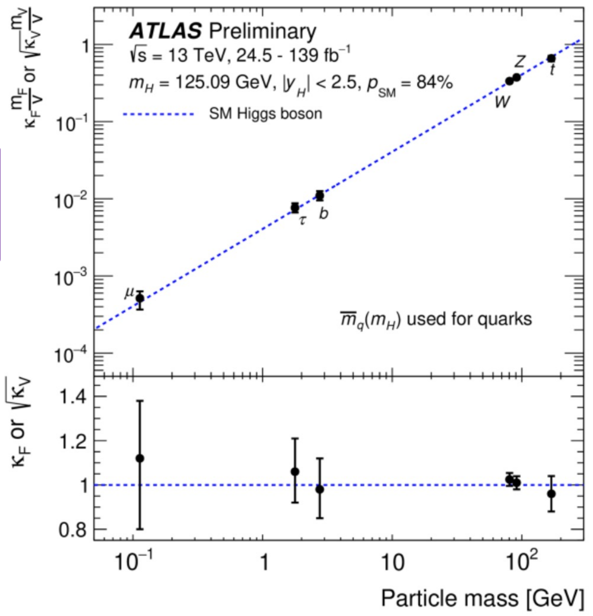
$$|d_e^{\mathrm{max}}| = 1.1 \times 10^{-29}\ e\ \mathrm{cm}\ \text{at}\ 90\%\,\mathrm{C.\,L.}$$

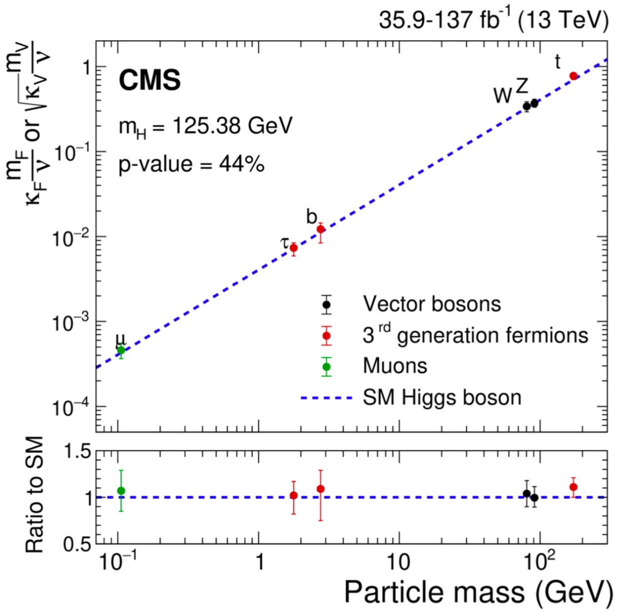
Motivation III – Energy Frontier

- LHC results of Higgs discovery and measurement of physical properties.
  - Only known elementary spin zero particle, i.e. a SCALAR, with SM Higgs boson properties (short range weak interaction from H->WW/ZZ, Yukawa interactions exist)!!
- No new elementary particles discovered with m ~ 1 TeV
  - New physics scale is high enough to be parametrized via higher dimensional operators.
- New physics via higher dimension operators
  - Use Higgs physics results from LHC to constrain these higher dim terms
  - Consider dimension six terms of Higgs- fermion fields with complex couplings

Motivation III Run II Probe Yukawa couplings

No BSM couplings





CMS-HIG-19-006
Arxiv 2009.04363

First time a Yukawa interaction is measured!!

- No evidence for new particles (coupling to the Higgs)
- Higgs and top mass values

implications for vacuum stability

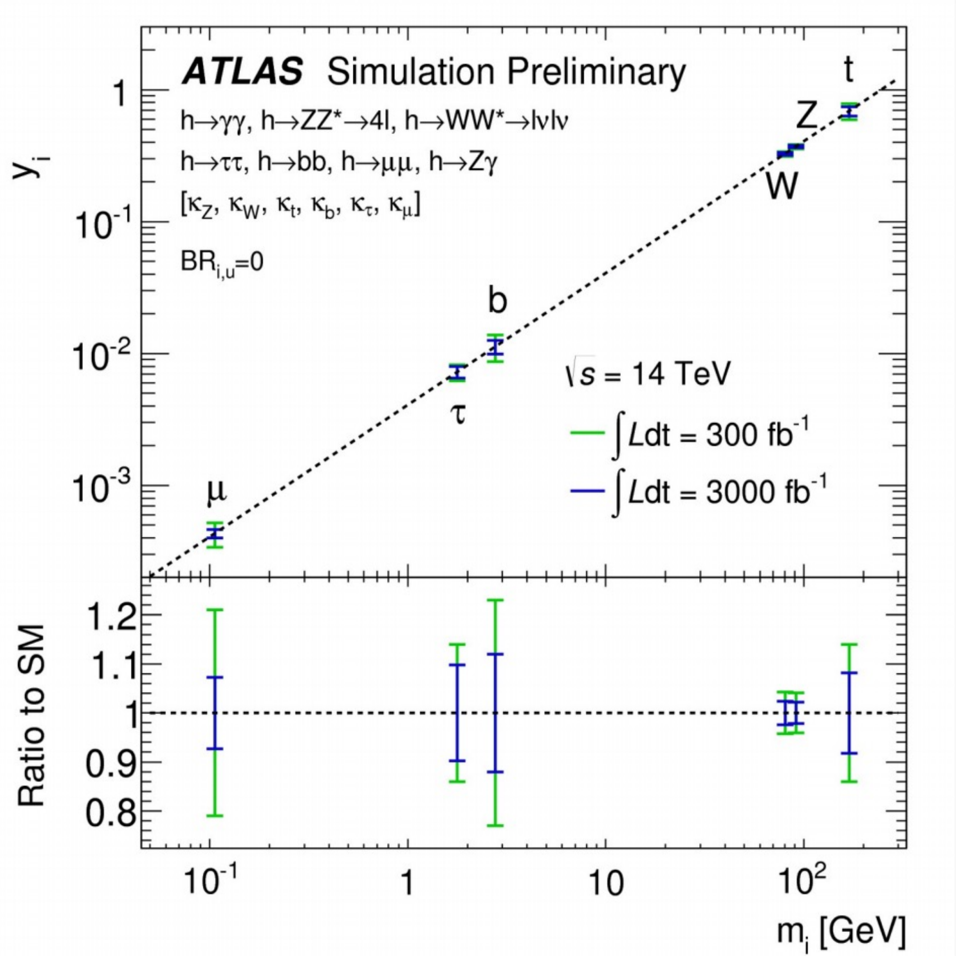
nature of EW symmetry breaking

electroweak phase transition

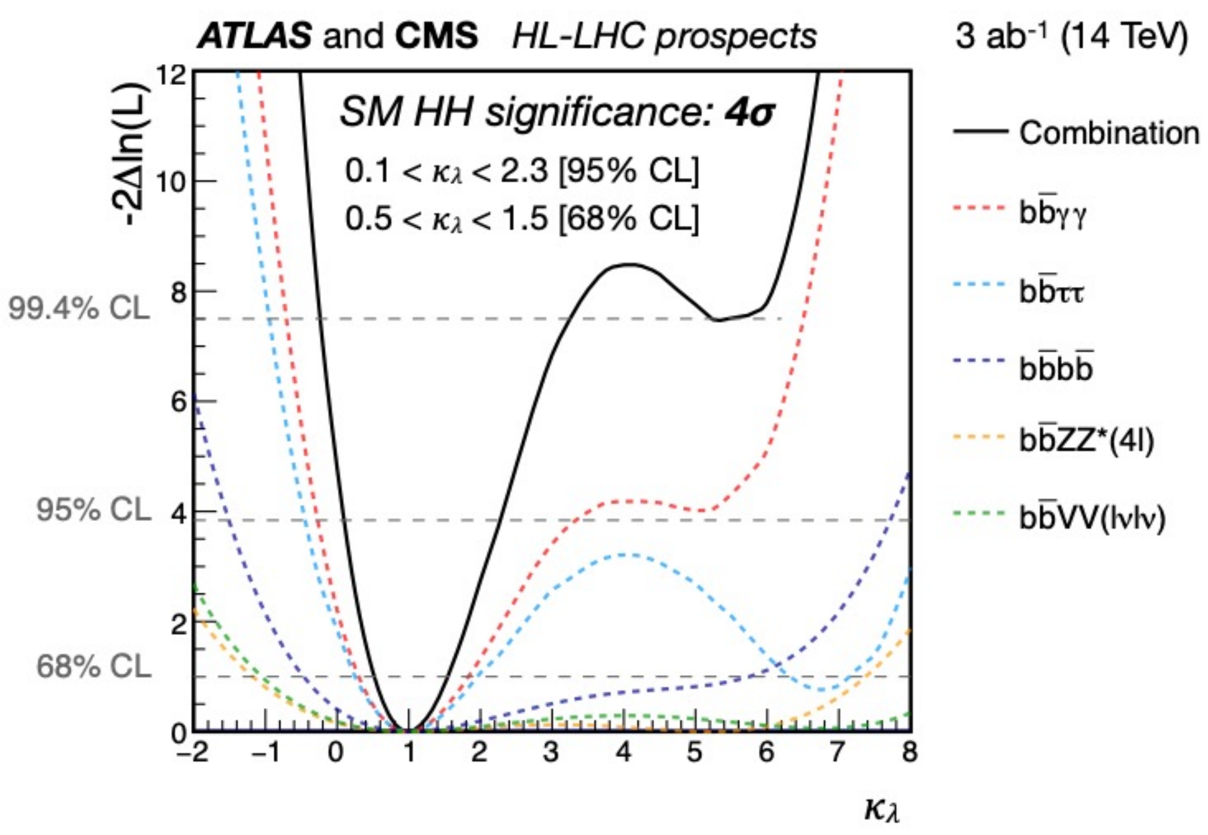
Want to measure Higgs self-coupling to understand the scalar potential, crucial for EWSB

HL-LHC projections

Improved precision ~ 50%
Can exclude $\kappa_\lambda = 0$ at 95% CL



Precision ~ 10%



FCC_{hh} expected sensitivity of κ_λ ~ 5%

SM EFT Framework

- Dim-6 term with real and imaginary Yukawa in Lagrangian:

$$\mathrm{L}_{\mathrm{Yuk}} = y_f \overline{F_L} F_R H + \frac{1}{\Lambda^2}(X_R^f + iX_I^f)|H|^2 \overline{F_L} F_R H + \mathrm{h.c.}$$

$$H = \frac{1}{\sqrt{2}}(v + h)$$

- Allows for new CPV interactions
- Changes the fermion mass and the corresponding Yukawa coupling relation.

Parametrize by ratio of dim 6 to dim 4 contribution to the fermion mass:

$$T_R^f \equiv \frac{v^2}{2\Lambda^2}\frac{X_R^f}{y_f}, \qquad T_I^f \equiv \frac{v^2}{2\Lambda^2}\frac{X_I^f}{y_f}$$

Parameters in SMEFT

$$\tan\theta_f = \frac{T_I^f}{1+T_R^f}$$

$$m_f = \frac{y_f v}{\sqrt{2}}\sqrt{(1+T_R^f)^2 + T_I^{f2}}$$

Mass and Yukawa coupling in real mass basis

$$\lambda_f = \frac{y_f}{\sqrt{2}} \frac{1+4T_R^f+3T_R^{f2}+3T_I^{f2}+2iT_I^f}{\sqrt{(1+T_R^f)^2+T_I^{f2}}}$$

$$\left(\frac{y_f}{y_f^{\mathrm{SM}}}\right)^2 = \frac{1}{(1+T_R^f)^2+T_I^{f2}}$$

Constraining SMEFT

- Experimental results can constrain the complex couplings via:
  - New contributions to cosmological observations, Y_B
  - New contributions to Higgs production and decay rates at colliders
  - New contributions to EDMs

Basics of EWBG

Kuzmin, Rubakov, Shaposhnikov ‘85

- Initial hot plasma with zero net baryon number with EW symmetry.
- As Universe expands and cools until EWPT around T ~ 100 GeV
- Bubbles of the broken phase nucleate and expand to fill the Universe.

- Necessary to have new physics
  - CP violation sources: plasma particles CPV interactions with the bubble wall
  - Strong first order phase transition: suppress sphaleron transitions in the broken phase

Electroweak Phase Transition

Assume:

- New degrees of freedom that produce a strong first order EWPT
- These do not affect the CPV interactions with bubble wall we are going to consider.
- No new sources of CPV from these new degrees of freedom.

There are important parameters such as the wall velocity and wall width that need to be obtained In a specific model. We will simply take on some benchmark values for them in this analysis.

Main processes for EWBG

- Charged fermion plasma particles CPV interactions with the bubble wall generate a chiral asymmetry, while CP-conserving interactions wash out the generated asymmetry.
- The strong sphaleron process produces further washout in the quark sector.
- Remaining asymmetry diffuses into the symmetric phase. Diffusion is dominantly affected by gauge interactions, more efficient for leptons than for quarks.
- The weak sphaleron process is efficient only in the symmetric phase, acting on left-handed multiplets and changing baryon number.
- The chemical potential due to the chiral asymmetry induces a preferred direction for the weak sphaleron, thus generating a baryon asymmetry.
- Finally, the bubble wall catches up and freezes in the resulting baryon number density in the broken phase.

SMEFT implications for EW Baryogenesis

Full dynamics given by set of coupled equations:

$$\partial_\mu f^\mu = -\Gamma^f_M \mu^f_M - \Gamma^f_Y \mu^f_Y + \Gamma^f_{ss}\mu_{ss} - \Gamma^f_{ws}\mu^f_{ws} + S_f$$

$$\partial_\mu f^\mu \approx v_w f' - D_f f''$$

SMEFT implications for EW Baryogenesis

Full dynamics given by set of coupled equations:

$$\partial_\mu f^\mu = -\Gamma_M^f \mu_M^f - \Gamma_Y^f \mu_Y^f + \Gamma_{ss}^f \mu_{ss} - \Gamma_{ws}^f \mu_{ws}^f + S_f$$

CPV Source term

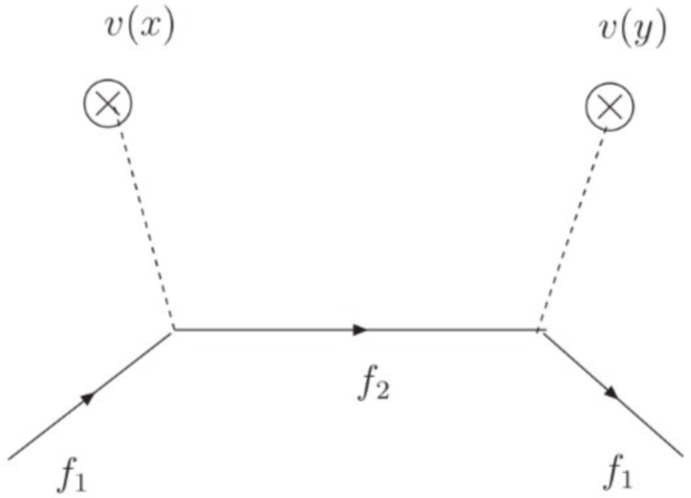
$$\partial_\mu f^\mu \approx v_w f' - D_f f''$$

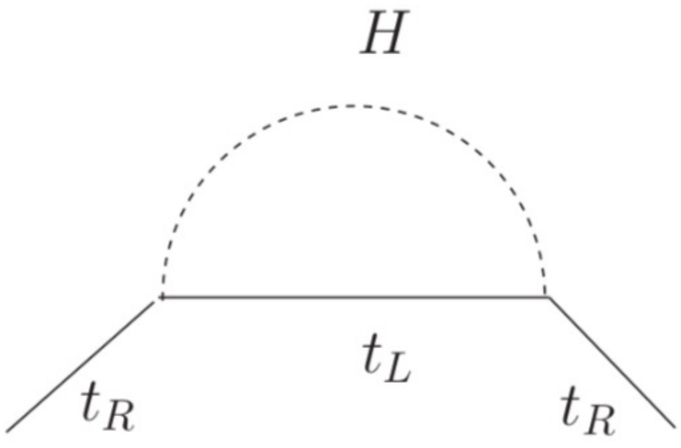
wall velocity

Diffusion constant

Source, relaxation and Yukawa terms

Use vev-insertion approx.





Lee et al

$$S_f \propto \mathcal{I}m(m_f^* m_f') \propto y_f^2 T_l^f$$

SMEFT implications for EW Baryogenesis

Full dynamics given by set of coupled eqns:

$$\partial_\mu f^\mu = -\Gamma^f_M \mu^f_M - \Gamma^f_Y \mu^f_Y + \Gamma^f_{\rm ss} \mu_{\rm ss} - \Gamma^f_{\rm ws} \mu^f_{\rm ws} + S_f$$

Relaxation terms

Yukawa terms

Strong sphaleron

Weak sphaleron

Changes in CP-even rates

$$\Gamma_M \to \left[\frac{(1 + r_{N0}^2 T_R^f)^2 + (r_{N0}^2 T_I^f)^2}{(1 + T_R^f)^2 + T_I^{f2}}\right] \Gamma_M$$

$$\Gamma_Y \to \left[\frac{(1 + 3r_{N0}^2 T_R^f)^2 + (3r_{N0}^2 T_I^f)^2}{(1 + T_R^f)^2 + T_I^{f2}}\right] \Gamma_Y$$

Baryon Asymmetry of the Universe

Using benchmark parameters

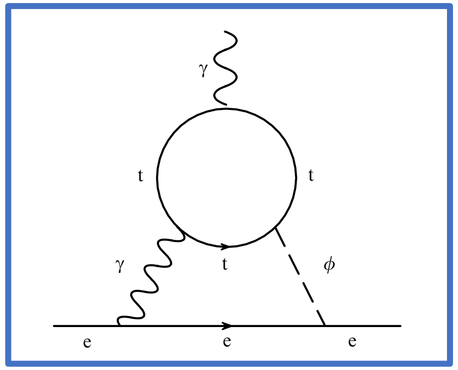
$T_R^f = 0$

$$Y_B = 8.6 \times 10^{-11} \times (51\, T_l^t - 23\, T_l^\tau - 0.44\, T_l^b)$$

BAU for values:

$$|T_l^t| = \mathcal{O}(0.02), \quad |T_l^\tau| = \mathcal{O}(0.04), \quad |T_l^b| > 1$$

SMEFT implications for (e)-EDMs



ACME bound $$|d_e^{\mathrm{max}}| = 1.1 \times 10^{-29}\ e\ \mathrm{cm}\ \text{at}\ 90\%\ \mathrm{C.L.}$$

$$\frac{d_e^{(t)}}{e} \simeq -\frac{32\sqrt{2}}{3}\frac{e^2}{(16\pi^2)^2}\frac{m_e}{v^2}\left[\left(2+\ln\frac{m_t^2}{m_h^2}\right)\left(\frac{y_t}{y_t^{\mathrm{SM}}}\right)^2 T_l^t\right]$$

Panico et al ‘19

$$\frac{d_e^{(b)}}{e} \simeq -\frac{32\sqrt{2}}{3}\frac{e^2}{(16\pi^2)^2}\frac{m_e}{v^2}\left[\frac{1}{4}\left(\frac{\pi^2}{3}+\ln^2\frac{m_b^2}{m_h^2}\right)\frac{m_b^2}{m_h^2}\left(\frac{y_b}{y_b^{\mathrm{SM}}}\right)^2 T_l^b\right]$$

$$\frac{d_e^{(\tau,\mu)}}{e} \simeq -\frac{32\sqrt{2}}{3}\frac{e^2}{(16\pi^2)^2}\frac{m_e}{v^2}\left[\frac{3}{4}\left(\frac{\pi^2}{3}+\ln^2\frac{m_{\tau,\mu}^2}{m_h^2}\right)\frac{m_{\tau,\mu}^2}{m_h^2}\left(\frac{y_{\tau,\mu}}{y_{\tau,\mu}^{\mathrm{SM}}}\right)^2 T_l^{\tau,\mu}\right]$$

e-EDMs of only third generation fermions

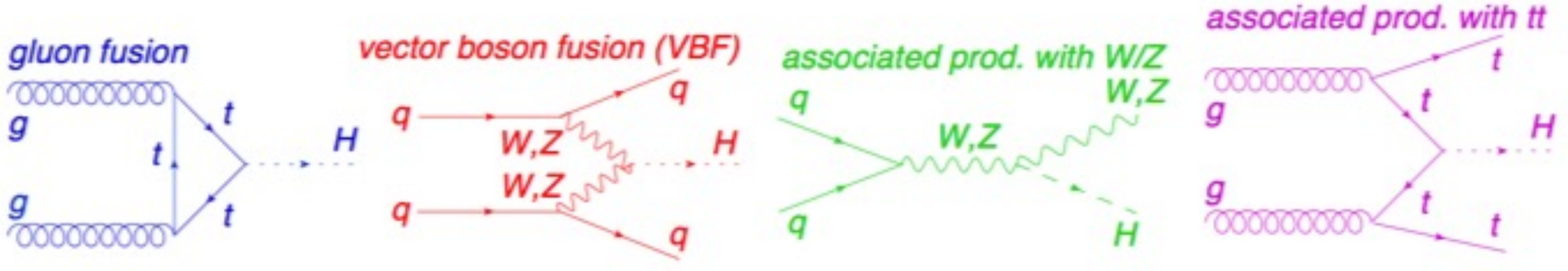
$$d_e \approx |d_e^{\rm max}| \left[2223 \left(\frac{y_t}{y_t^{\rm SM}}\right)^2 T_l^t + 9.6 \left(\frac{y_\tau}{y_\tau^{\rm SM}}\right)^2 T_l^\tau + 11.6 \left(\frac{y_b}{y_b^{\rm SM}}\right)^2 T_l^b\right]$$

So for, $y_f = \mathcal{O}(y_f^{\rm SM})$

$$T_l^t = \mathcal{O}(0.0004), \quad T_l^\tau = \mathcal{O}(0.1), \quad T_l^b = \mathcal{O}(0.09)$$

SMEFT implications for Colliders

- Modification of Higgs production and decay modes.



$$\mu_I^F \equiv \frac{\sigma_I(pp \to h) \cdot \Gamma(h \to F)/\Gamma_h}{[\sigma_I(pp \to h) \cdot \Gamma(h \to F)/\Gamma_h]_{\rm SM}}$$

$$r_f \equiv \frac{|\lambda_f|^2/|\lambda_f^{\rm SM}|^2}{|m_f|^2/|m_f^{\rm SM}|^2} = \frac{(1+3T_R^f)^2 + 9T_I^{f\,2}}{(1+T_R^f)^2 + T_I^{f\,2}}$$

Modified Production Rates, Decays and Total Width

Production Rates

$$\sigma_{\mathrm{ggF}}/\sigma_{\mathrm{ggF}}^{\mathrm{SM}} = \sigma_{tth}/\sigma_{tth}^{\mathrm{SM}} = r_t$$

$$\sigma_{Vh}/\sigma_{Vh}^{\mathrm{SM}} = \sigma_{\mathrm{VBF}}/\sigma_{\mathrm{VBF}}^{\mathrm{SM}} = 1$$

Decay Rates

$$\Gamma(h \to f\bar{f})/[\Gamma(h \to f\bar{f})]^{\mathrm{SM}} = r_f \quad (f = b, \tau, \mu)$$

Total Width

$$\Gamma_h/\Gamma_h^{\mathrm{SM}} = 1 + \mathrm{BR}_b^{\mathrm{SM}}(r_b - 1) + \mathrm{BR}_\tau^{\mathrm{SM}}(r_\tau - 1) + \mathrm{BR}_g^{\mathrm{SM}}(r_t - 1)$$

LHC Measurements

channel	experiment	$\sqrt{s}$/ TeV	$\mathscr{L}$ / fb^{-1}	comment	μ
$h \to \tau^+\tau^-$	ATLAS+CMS	7+8	$5 + 20$		$1.11^{+0.24}_{-0.22}$
	ATLAS	13	36.1	ggF, VBF	$1.09^{+0.35}_{-0.30}$
	CMS	13	77	ggF, $\bar{b}b$, VBF, Vh	0.75 ± 0.17
	ATLAS+CMS	7+8+13		all prod., priv. comb.	0.91 ± 0.13
$h \to \mu^+\mu^-$	ATLAS	13	139	upper bound at 95% C. L.	< 1.7
	CMS		35.9		< 2.9
$h \to \bar{b}b$	ATLAS	13	79.8	VBF+VH	1.23 ± 0.26
				$t\bar{t}h + th$	$0.79^{+0.60}_{-0.59}$
	CMS	7+8+13	41.3	VH (0-2ℓ, 2 b-tags+jets)	1.01 ± 0.22
				all prod.	1.04 ± 0.2
	ATLAS+CMS	7+8+13		VH, priv. comb.	0.98 ± 0.15
				all prod., priv. comb.	1.02 ± 0.14

+ all processes with t

Single flavor

$$\mu_f = \frac{r_f}{1 + \mathrm{BR}_f^{\mathrm{SM}}(r_f - 1)}$$

defines a circle in the (T_R, T_I) plane

$${T_I^f}^2 + (T_R^f - T_{R0}^f)^2 = R_T^2$$

For $\mu_f = 1$, can have $T_R^f, T_I^f \neq 0$, independent of $\mathrm{BR}_f^{\mathrm{SM}}$

Combined flavors

σ_I	$\Gamma(h \to F)$	Γ_h	f_1, f_2	process	dependence
SM	f_1	f_1, f_2	τ, b t, τ t, b	any production, $h \to \tau\tau, b\bar{b}$ Vh+VBF, $h \to \tau\tau$ Vh+VBF, $h \to b\bar{b}$	A
f_1	SM	f_1, f_2	$t, b/\tau$	ggF+tth, $h \to VV$	A
f_1	f_2	f_1, f_2	t, τ t, b	ggF+tth, $h \to \tau\tau$ ggF+tth, $h \to b\bar{b}$	B

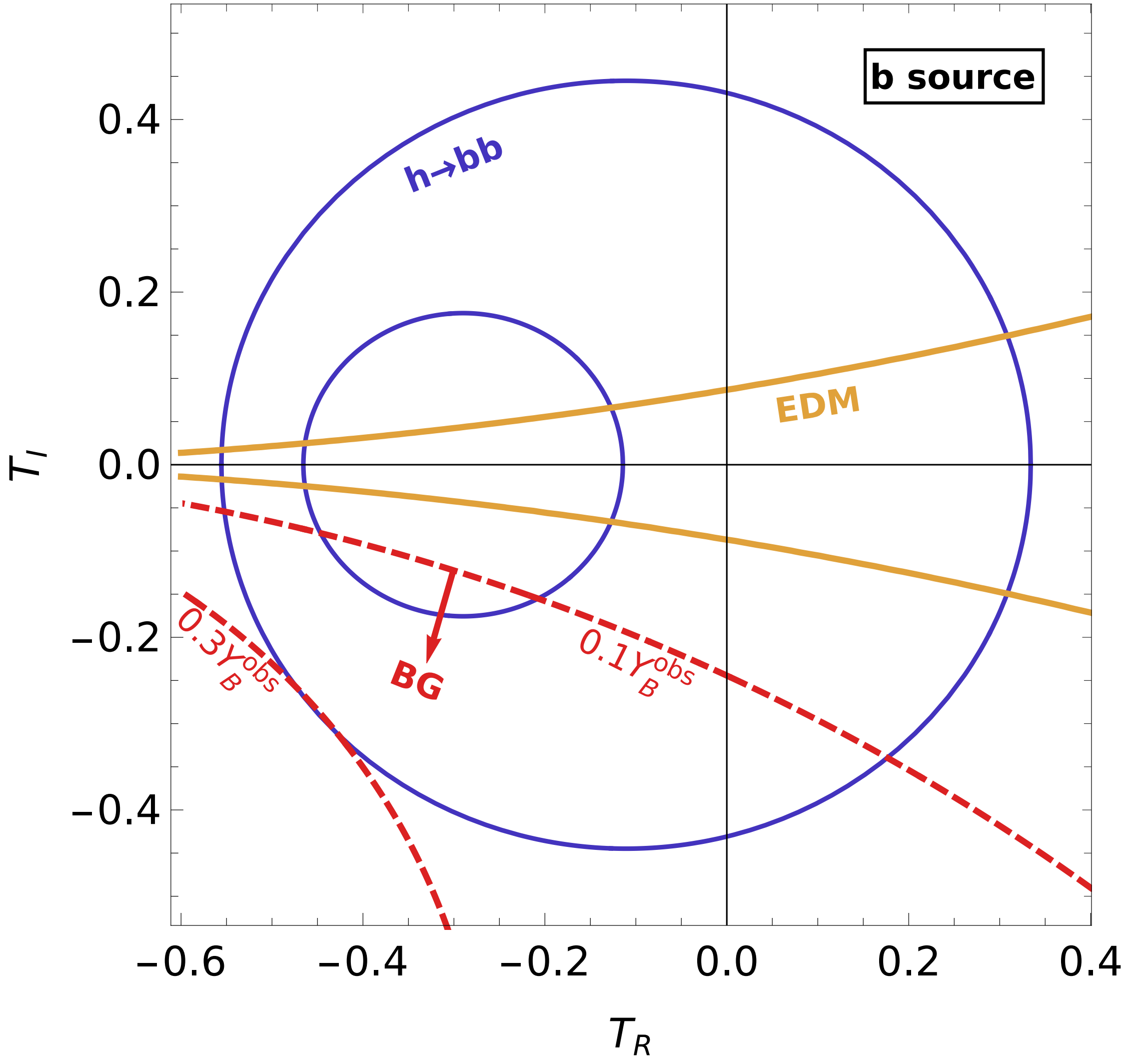
$$\text{A:} \qquad \mu_{\rm SM}^{f_1} = \mu_{f_1}^{\rm SM} = \frac{r_{f_1}}{\Gamma_h/\Gamma_h^{\rm SM}} = \frac{r_{f_1}}{1 + {\rm BR}_{f_1}^{\rm SM}(r_{f_1} - 1) + {\rm BR}_{f_2}^{\rm SM}(r_{f_2} - 1)}$$

$$\text{B:} \qquad \mu_{f_1}^{f_2} = \frac{r_{f_1}\, r_{f_2}}{\Gamma_h/\Gamma_h^{\rm SM}} = \frac{r_{f_1}\, r_{f_2}}{1 + {\rm BR}_{f_1}^{\rm SM}(r_{f_1} - 1) + {\rm BR}_{f_2}^{\rm SM}(r_{f_2} - 1)}$$

Results: Single flavor features

- $Y_B, |d_e| \propto (y_f/y_f^{SM})^2 T_I^f$, except for the top quark. For $f \neq t$, contours of constant Y_B are also contours of constant d_e.
- Y_B^t is approximately constant in T_R^t due to the large Yukawa coupling contributing to its thermal mass.
- Y_B dependence on T_R^f is mild. Negative values of T_R generate a larger baryon asymmetry.
- $\mu_f = 1$ defines a circle through the SM point $T_I^f = T_R^f = 0$.
- Experimental bounds on μ_f constrain the dim-6 operators of each species to an annulus in the T_R^f, T_I^f plane.

Third generation quarks --bottom

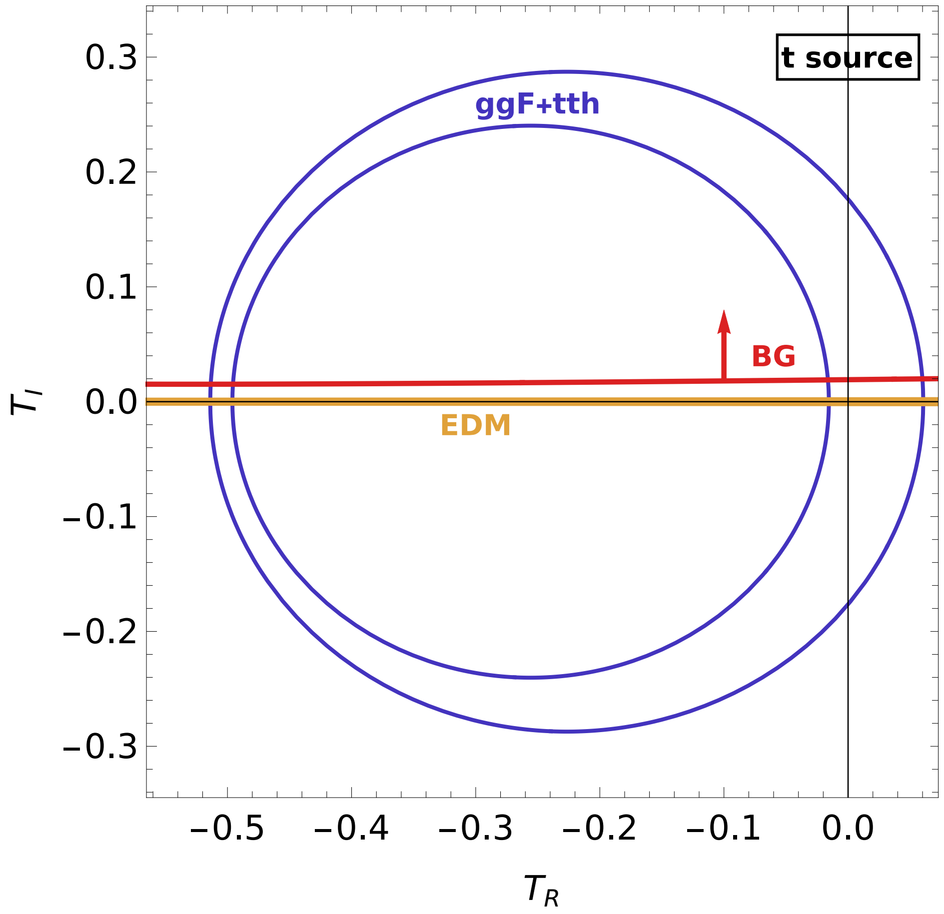


All production modes combined

$$\mu_{b\bar{b}} = 1.02 \pm 0.14$$

dominated by μ_{Vh}^{bb}

Third generation quarks -- top

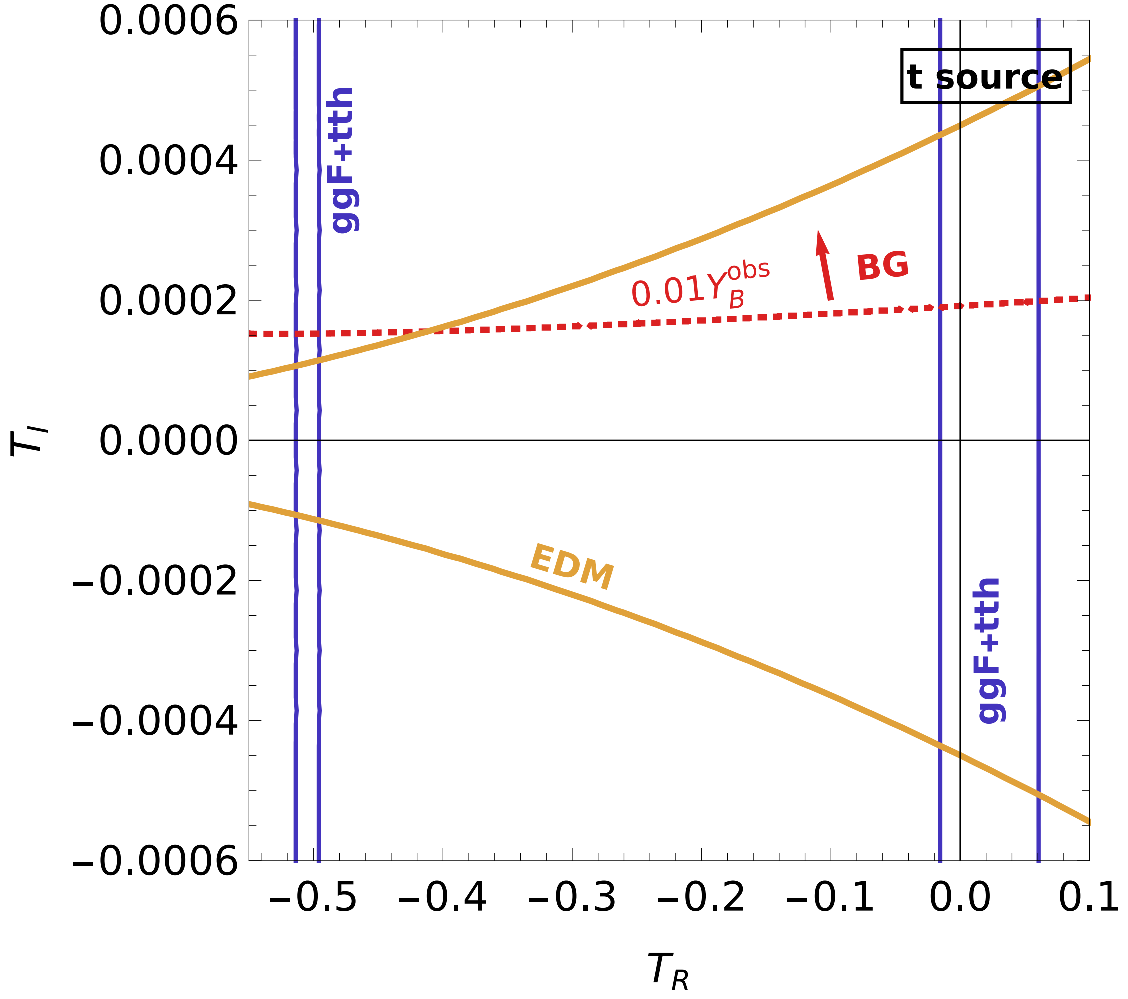


Constrained by $\mu_{\rm ggF}$, μ_{tth} and $\mu_{\gamma\gamma}$

all decays

$$\mu_{{\rm ggF}+t\bar{t}h} = 1.09 \pm 0.08$$

Third generation quarks –top (zoomed)



Constrained by $\mu_{\rm ggF}$, μ_{tth} and $\mu_{\gamma\gamma}$

$$\mu_{{\rm ggF}+t\bar{t}h} = 1.09 \pm 0.08$$

Leptons --muon

$$\frac{Y_B^{(\mu)}}{8.6 \times 10^{-11}} = \frac{d_e^{(\mu)}}{4.1 \times 10^{-30} \ e \ \mathrm{cm}}$$

$$\mu_{\mu^+\mu^-} = \frac{\Gamma(h \to \mu^+\mu^-)}{[\Gamma(h \to \mu^+\mu^-)]_{\mathrm{SM}}}$$

$$\mu_{\mu^+\mu^-} = \frac{(1 + 3\,T_R^{\mu})^2 + 9\,T_I^{\mu 2}}{(1 + T_R^{\mu})^2 + T_I^{\mu 2}}$$

$$\mu_{\mu^+\mu^-}^{\mathrm{CMS}} < 2.9 \ \mathrm{at} \ 95\% \ \mathrm{C.L.}$$

$$\mu_{\mu^+\mu^-}^{\mathrm{ATLAS}} < 1.7 \ \mathrm{at} \ 95\% \ \mathrm{C.L.}$$

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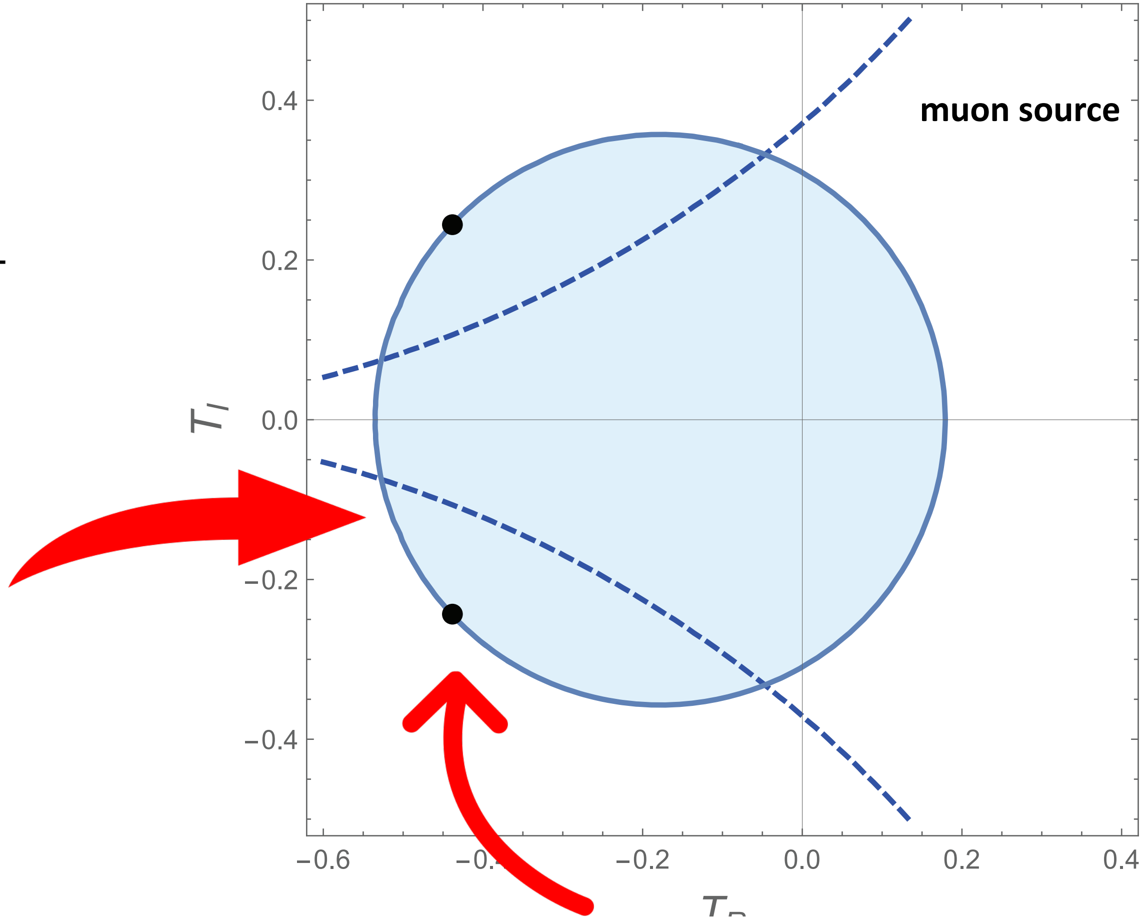
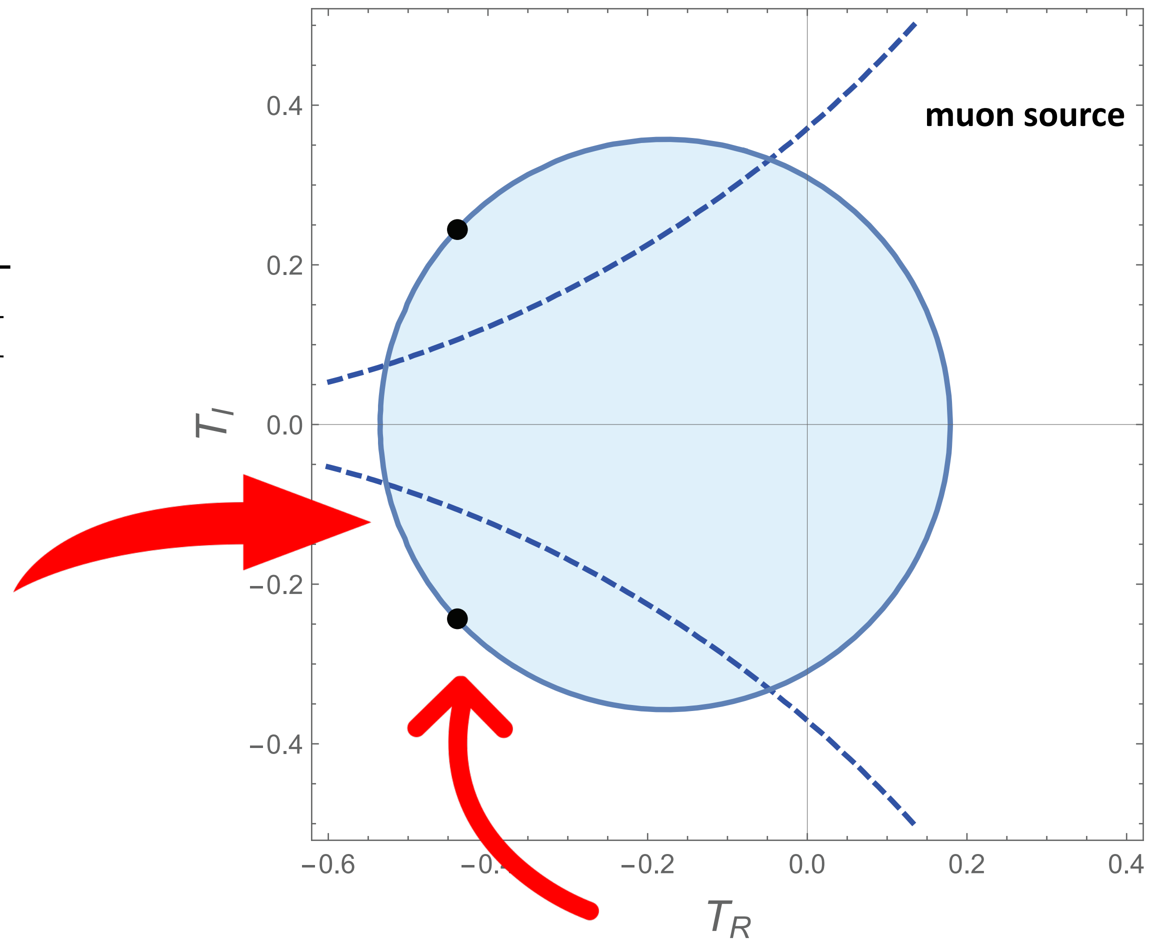


$$|Y_B^{(\mu)}|_{\max} = 1.4 \times 10^{-11}$$
$$|d_e^{(\mu)}|_{\max} = 6.5 \times 10^{-31} \; e \text{ cm}$$

Leptons --muon

$$\mu_{\mu^+\mu^-} = \frac{\Gamma(h \to \mu^+\mu^-)}{[\Gamma(h \to \mu^+\mu^-)]_{\rm SM}}$$

$$\mu^{\rm CMS}_{\mu^+\mu^-} < 2.9 \text{ at } 95\% \text{ C.L.}$$
$$\mu^{\rm ATLAS}_{\mu^+\mu^-} < 1.7 \text{ at } 95\% \text{ C.L.}$$



More recently,

$$\mu^{ATLAS}_{\mu^+\mu^-} = 1.2 \pm 0.6$$
$$\mu^{CMS}_{\mu^+\mu^-} = 1.19^{+0.65}_{-0.53}$$

$$|Y_B^{(\mu)}|_{\rm max} = 1.4 \times 10^{-11}$$
$$|d_e^{(\mu)}|_{\rm max} = 6.5 \times 10^{-31} \; e \text{ cm}$$

Leptons --muon

$\mu_{\mu^+\mu^-}$ CP-even observable

- The effective muon Yukawa coupling is not dominated by contributions from non-renormalizable terms.
- Is constraining a CP-odd observable, the baryon asymmetry, which is not dominated by a complex muon Yukawa coupling

$$|Y_B^{(\mu)}|_{\max}$$

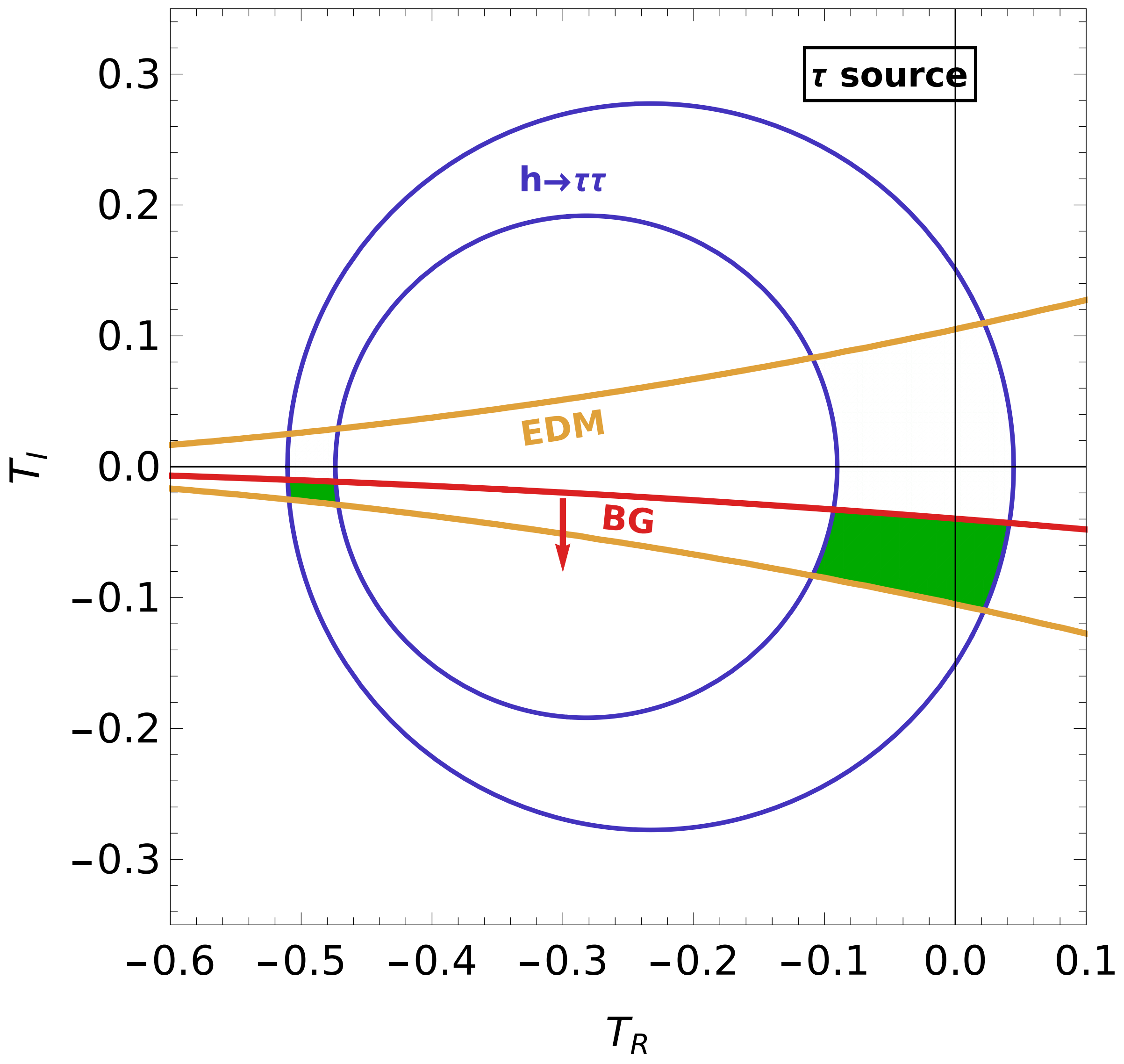
- A complex muon coupling could account for as much as 16% of Y_B, from current collider constraints.

Leptons- tau

$\Gamma(h \to \tau^+\tau^-)$ and Γ_h

All production modes

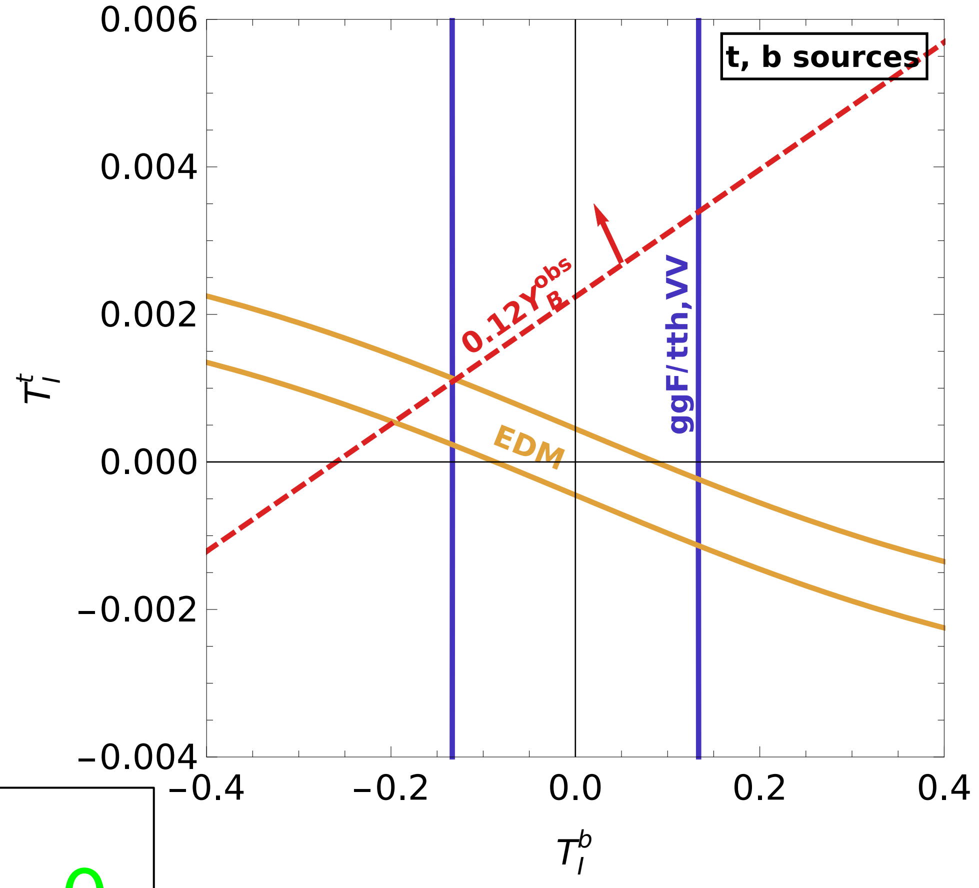
$$\mu_{\tau^+\tau^-} = 0.91 \pm 0.13$$

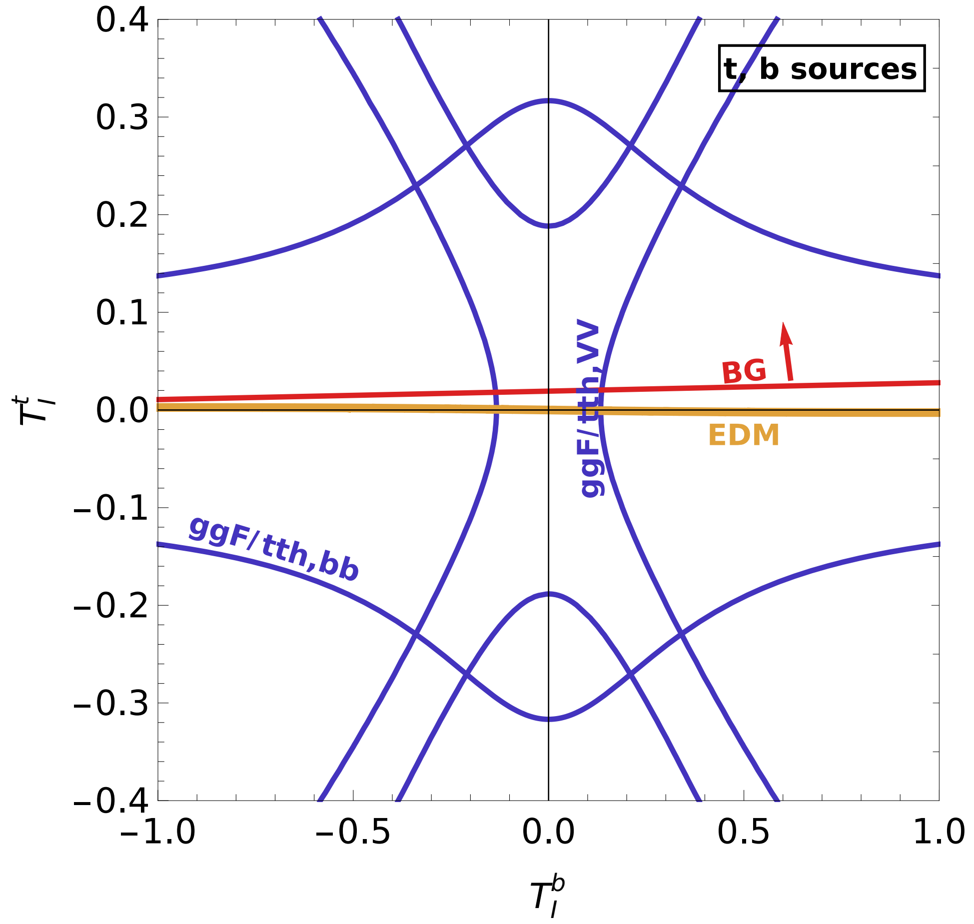


Combined Sources t-b

$$\mu^{b\bar{b}}_{t\bar{t}h+ggF} = 0.88 \pm 0.43$$
$$\mu^{bb}_{VH} = 0.98 \pm 0.15$$
$$\mu^{VV}_{\mathrm{ggF}+tth} = 1.08 \pm 0.08$$

$$Y_B^{(t+b)} \lesssim 0.12\, Y_B^{\mathrm{obs}}$$





$$T_R^f = 0$$

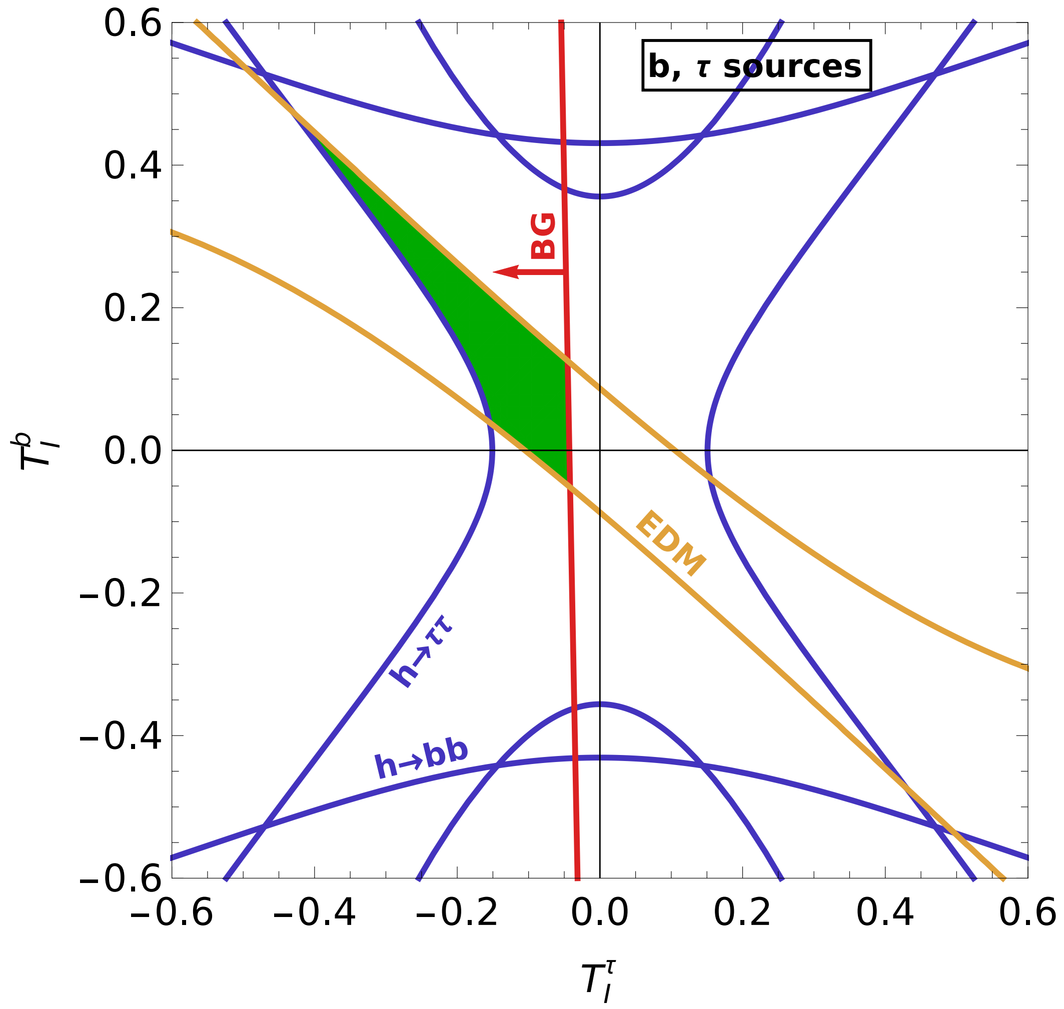
Combined Sources tau- b

No modification to production rates

$\mu_{\tau^+\tau^-}$

$\mu_{b\bar{b}}$

Only Constraints

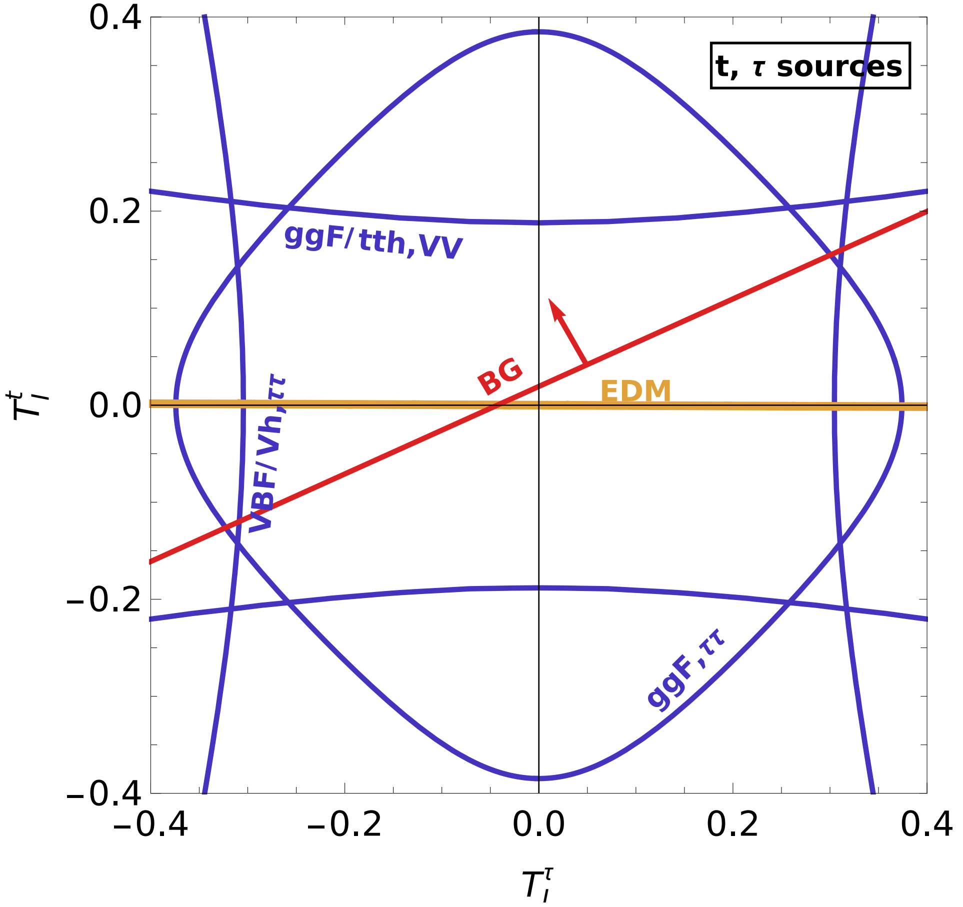


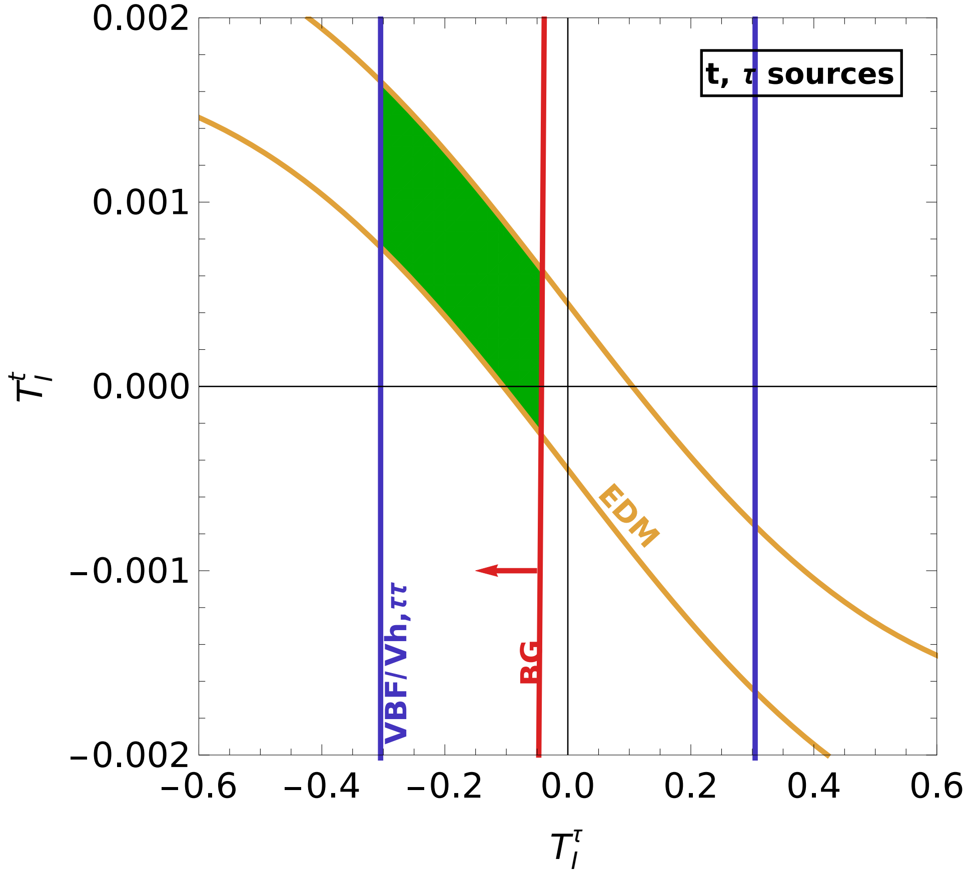
$$Y_B^{b+\tau,\mathrm{max}}(T_I^\tau = -0.4, T_I^b = +0.4) \simeq 7.8\, Y_B^{\mathrm{obs}}$$

$$T_R^f = 0$$

Combined sources tau-t

$$\mu^{\tau\tau}_{\rm ggF} = 0.99 \pm 0.44$$
$$\mu^{\tau\tau}_{{\rm VBF}+Vh} = 1.09 \pm 0.26$$
$$\mu^{VV}_{{\rm ggF}+tth} = 1.08 \pm 0.08$$





$$T^f_R = 0$$

$$Y_B^{t+\tau,\rm max} = Y_B^{t+\tau}(T_I^\tau = -0.3,\, T_I^t = +0.0016) \simeq 6.4\, Y_B^{\rm obs}$$

SM-like solutions $Y_B = Y_B^{\rm obs}$ with $d_e \simeq 0$ and $\mu_l^F \simeq 1$

Choose

T_l^τ and T_l^b such that $d_e = 0$,

T_R^τ and T_R^b such that $\mu_b = \mu_\tau = 1$

$$Y_B^{b+\tau,\rm max}(d_e = 0, \mu_b = \mu_\tau = 1) = 10.25\, Y_B^{\rm obs}$$

Recap + Signature

With two flavours:

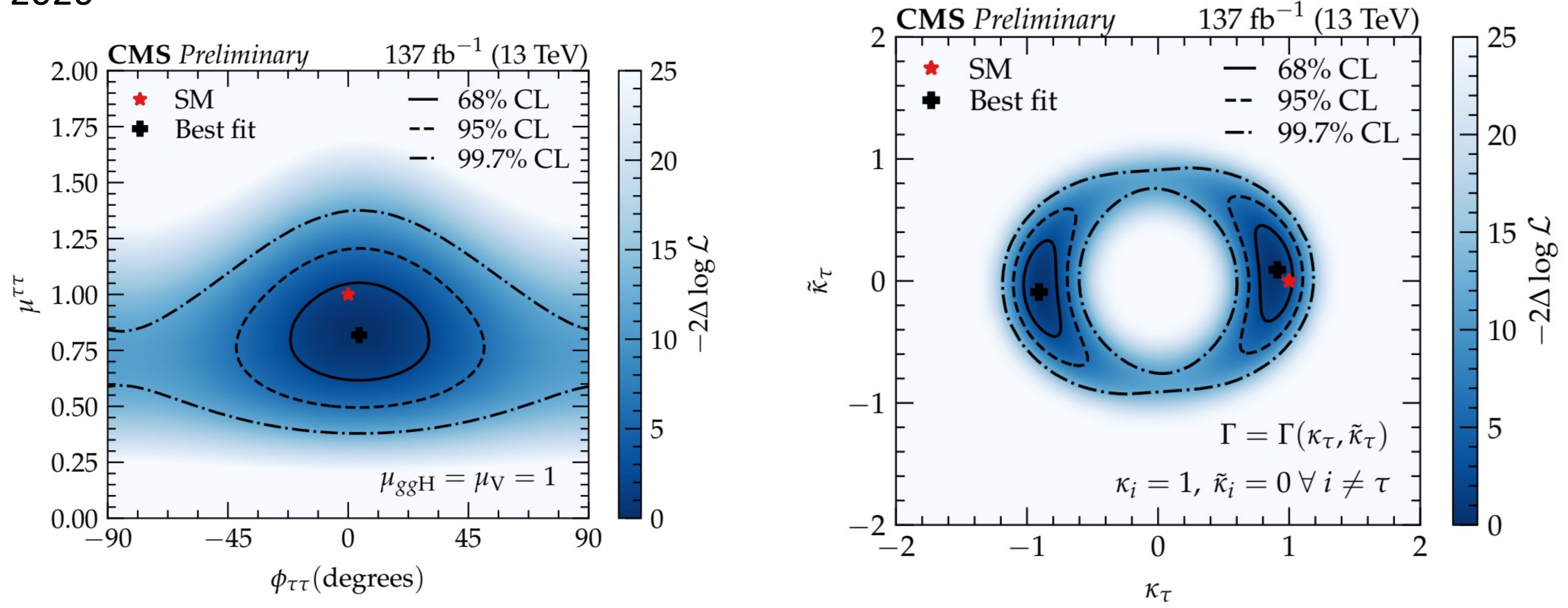
- We can produce the BAU without any deviation of μ_I^F
- No CPV signal from a single EDM, ……other additional EDMs??
- For BAU and EDMs additive contributions of different Yukawa couplings.

μ_I^F measurements at colliders is flavor specific.

CP violation in H->tau tau to determine T_I^τ by measuring angular distributions in Higgs boson decays to pairs of tau leptons.

Constraints on Tau CP mixing angle

CMS-PAS – HIG 20-006
Dow 2020



Implication for EFT Scales

Upper bounds on $T_{I,R}$ from collider and EDMs.

$$\Lambda/\sqrt{X^f_{R,I}} \gtrsim \frac{v}{\sqrt{2}} \frac{1}{(y_f T_{R,I})^{1/2}} \sim \mathrm{few} - \mathcal{O}(10)\ \mathrm{TeV}$$

For Y_B^{obs}, T_I^τ in the range $0.01 - 0.1$

$$\Lambda/\sqrt{X_I^\tau} \lesssim 18\ \mathrm{TeV}\ (0.01/T_I^\tau)^{1/2}$$

Flavour symmetries

Alonso-Gonzalez, Merlo, Pokorski, 20

Electron contribution to EDM

- MFV

$$T_I^t = T_I^c = T_I^u, \quad T_I^b = T_I^s = T_I^d, \quad T_I^\tau = T_I^\mu = T_I^e.$$

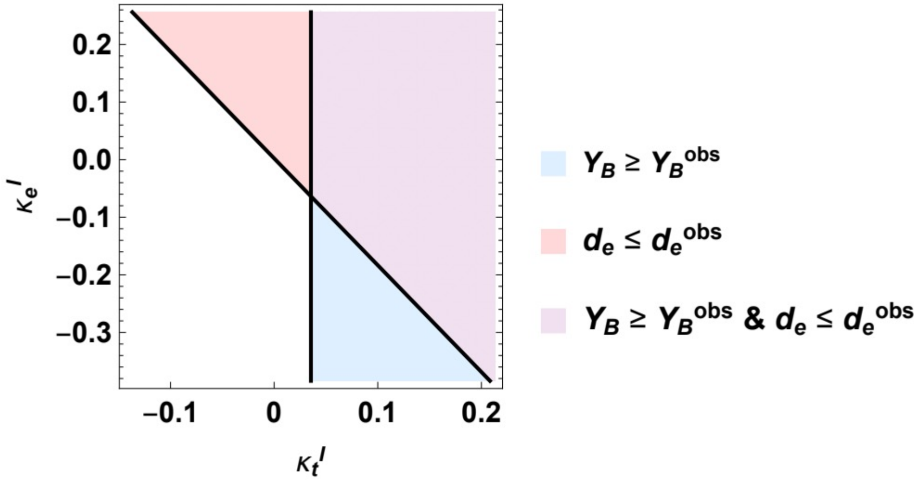
Constrains BAU from tau source

Constraints from other fermions

See Aharony, 21

Table I: *The BAU calculated following the full set of transport equations.* Y_B^f *is the BAU resulting from* S_f. *Collider constraints are at* ∼ 95% *C.L.* [3, 14–17]. *EDM constraints are at* 90% *C.L.* [7, 12] *for all, except for the bottom and charm, for which the nEDM constraints are at* 68% *C.L.* [10].

Source	BAU, Y_B^f	Higgs decay	eEDM	nEDM	maximal % $Y_B^{\rm obs}$
S_τ	$-9.9\cdot10^{-10}\cdot\kappa_\tau^I$	$\lvert\kappa_\tau\rvert\lesssim1.1$	$\lvert\kappa_\tau^I\rvert\lesssim0.3$	-	337%
S_μ	$-1.0\cdot10^{-11}\cdot\kappa_\mu^I$	$\lvert\kappa_\mu\rvert\lesssim1.4$	$\lvert\kappa_\mu^I\rvert\lesssim31$	-	17%
S_b	$-2.1\cdot10^{-11}\cdot\kappa_b^I$	$\lvert\kappa_b\rvert\lesssim1.7$	$\lvert\kappa_b^I\rvert\lesssim0.2$	$\lvert\kappa_b^I\rvert\lesssim7.4$	5.8%
S_t	$2.4\cdot10^{-9}\cdot\kappa_t^I$	$\lvert\kappa_t\rvert\lesssim1.2$	$\lvert\kappa_t^I\rvert\lesssim1.2\cdot10^{-3}$	-	3.3%
S_c	$-2.7\cdot10^{-12}\cdot\kappa_c^I$	$\lvert\kappa_c\rvert\lesssim3.3$	$\lvert\kappa_c^I\rvert\lesssim0.4$	$\lvert\kappa_c^I\rvert\lesssim13.6$	1.1%
S_s	$-1.6\cdot10^{-14}\cdot\kappa_s^I$	$\lvert\kappa_s\rvert\lesssim43$	$\lvert\kappa_s^I\rvert\lesssim109$	$\lvert\kappa_s^I\rvert\lesssim4.5$	0.08%
S_d	$-3.8\cdot10^{-17}\cdot\kappa_d^I$	$\lvert\kappa_d\rvert\lesssim890$	$\lvert\kappa_d^I\rvert\lesssim2.3\cdot10^4$	$\lvert\kappa_d^I\rvert\lesssim0.14$	$6\cdot10^{-6}$%
S_u	$-8.1\cdot10^{-18}\cdot\kappa_u^I$	$\lvert\kappa_u\rvert\lesssim1900$	$\lvert\kappa_u^I\rvert\lesssim2.2\cdot10^4$	$\lvert\kappa_u^I\rvert\lesssim0.6$	$6\cdot10^{-6}$%
S_e	$-2.5\cdot10^{-16}\cdot\kappa_e^I$	$\lvert\kappa_e\rvert\lesssim266$	$\lvert\kappa_e^I\rvert\lesssim2.2\cdot10^{-3}$	-	$6\cdot10^{-7}$%



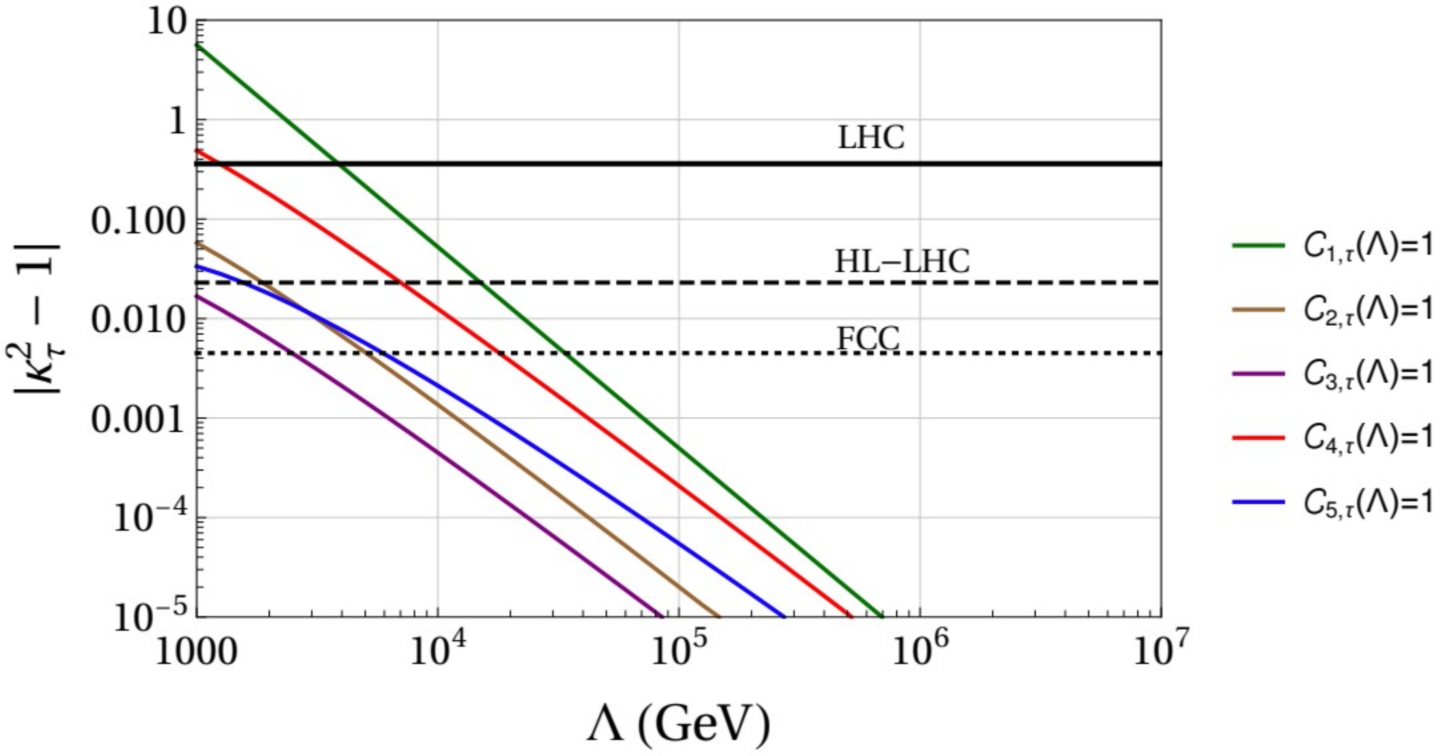
Conclusions

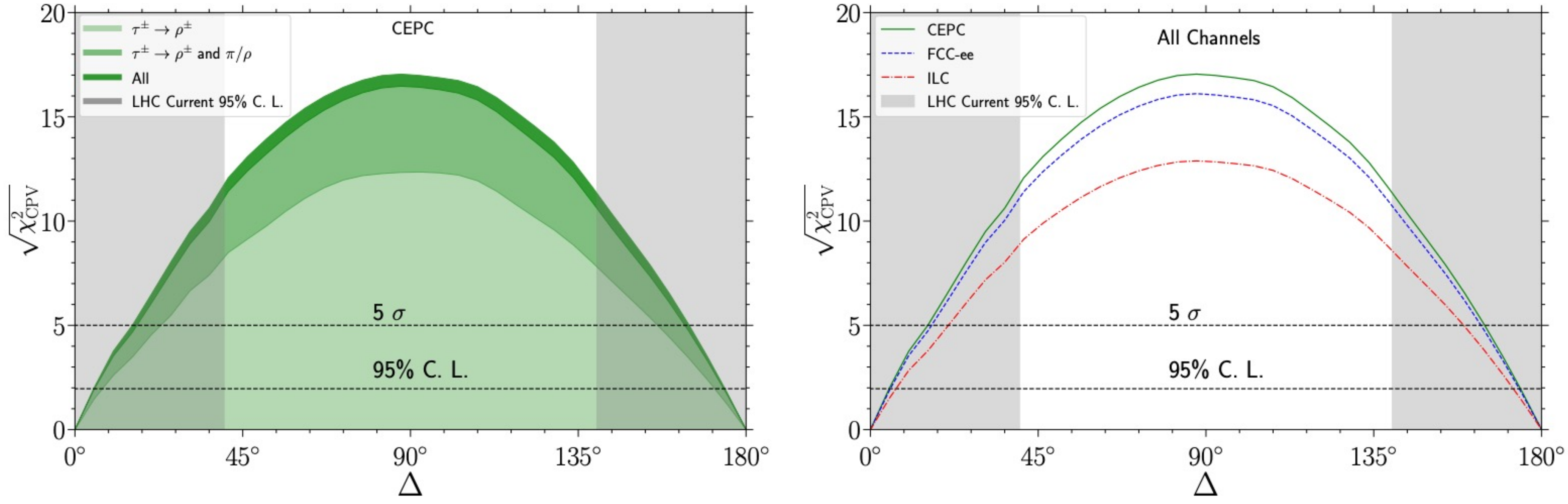
- Baryon asymmetry can be produced with only a tau CPV source.
- The CPV sources for the top and bottom cannot provide a large enough baryon asymmetry, due to EDM constraint.
- CPV source for the muon cannot provide large enough Y_B due to collider constraint h->mu mu.
- When multiple CPV sources (tau-t; tau-b, t-e) are present: cancellations to EDMs while enhancing $Y_B > Y_B^{\rm obs}$
- Smoking gun of tau CPV source is measuring CPV in Higgs boson decays to tau leptons.

Gracias!

Backup slides

Fafjer, Kamenik, Tammaro




CEPC
$\tau^\pm \to \rho^\pm$
$\tau^\pm \to \rho^\pm$ and π/ρ
All
LHC Current 95% C. L.
5 σ
95% C. L.
$\sqrt{\chi^2_{\rm CPV}}$
Δ
All Channels
CEPC
FCC-ee
ILC
LHC Current 95% C. L.
5 σ
95% C. L.
$\sqrt{\chi^2_{\rm CPV}}$
Δ

CP mixing angle for top