CP violation from dim-6 Yukawas

Baryogenesis, Higgs rates and EDMs

Elina Fuchs
Fermilab & UChicago

Fermilab

THE UNIVERSITY OF CHICAGO

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In collaboration with
Marta Losada (NYUAD)
Yossi Nir (Weizmann)
Yehonatan Viernik (Weizmann)

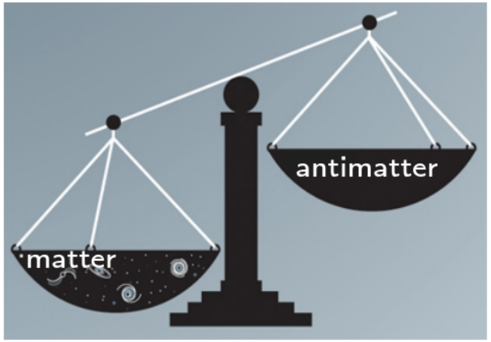
1911.08495 (μ) [in press, PRL]
2002.00099 (τ, t, b)
200n.YYYY (formalism)

The presented work was partly done at מכון ויצמן למדע WEIZMANN INSTITUTE OF SCIENCE Minerva Stiftung

CP violation for baryon asymmetry

Sakharov conditions for Baryogenesis

I. B number violation
II. CP violation
III. Out of thermal equilibrium

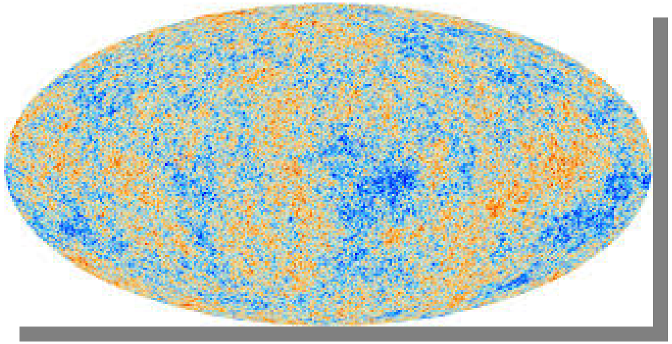


[adapted from quantumdiaries]

- Observed baryon asymmetry $\eta = \dfrac{n_B - n_{\bar{B}}}{n_\gamma} \sim 10^{-10}$
- SM: $\delta_{\rm CKM}$ and $\bar{\theta}_{\rm QCD} < 10^{-10}$ insufficient

Gavela, Hernandez, Orloff, Pene '93
Huet, Sather '94

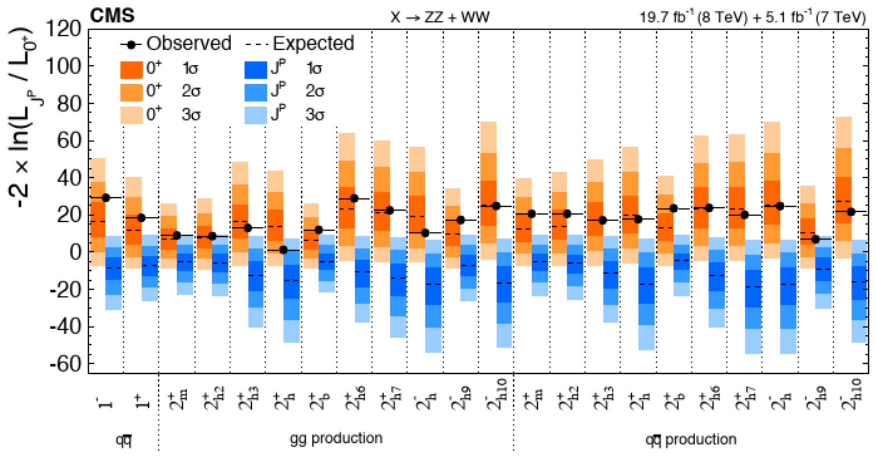
Need CP violation beyond the SM

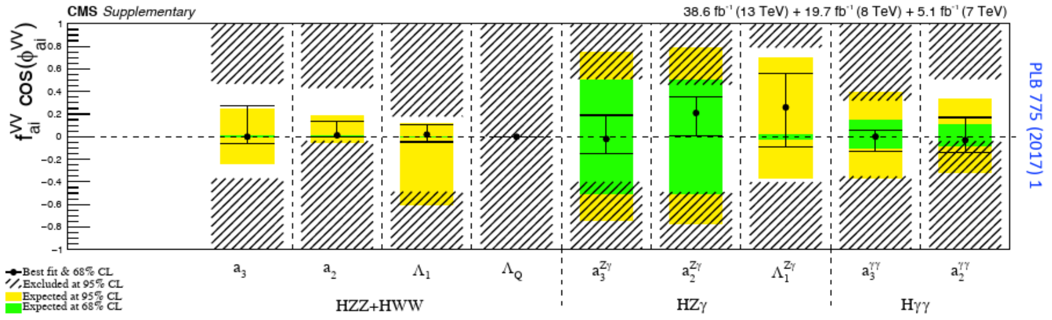


[PLANCK/ESA 2013]

CP violation in the Higgs sector

- Discovered Higgs compatible with $J^{PC} = 0^{++}$
- Small CP-odd component possible



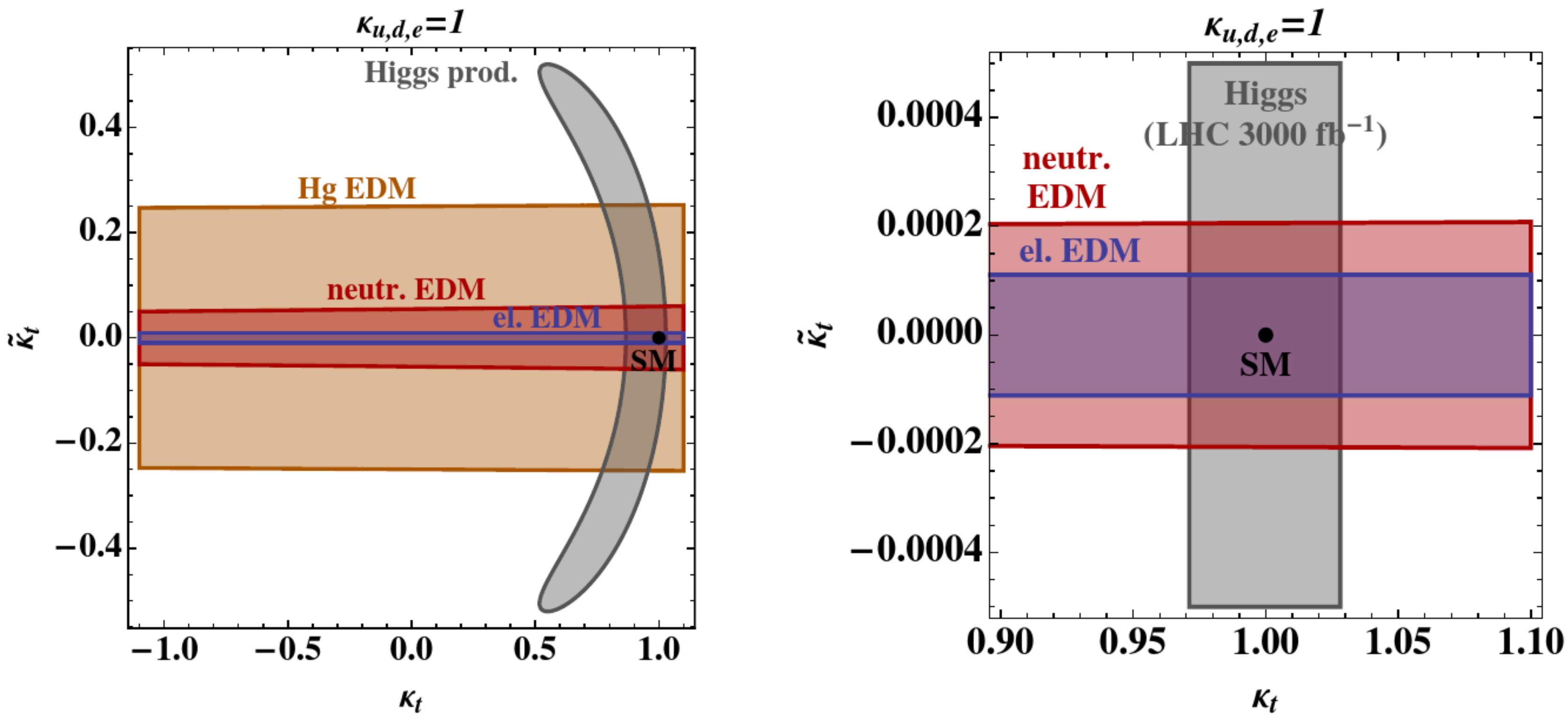


So far mostly searches for CPV in hVV

EDM & LHC limits CPV Yukawas

top

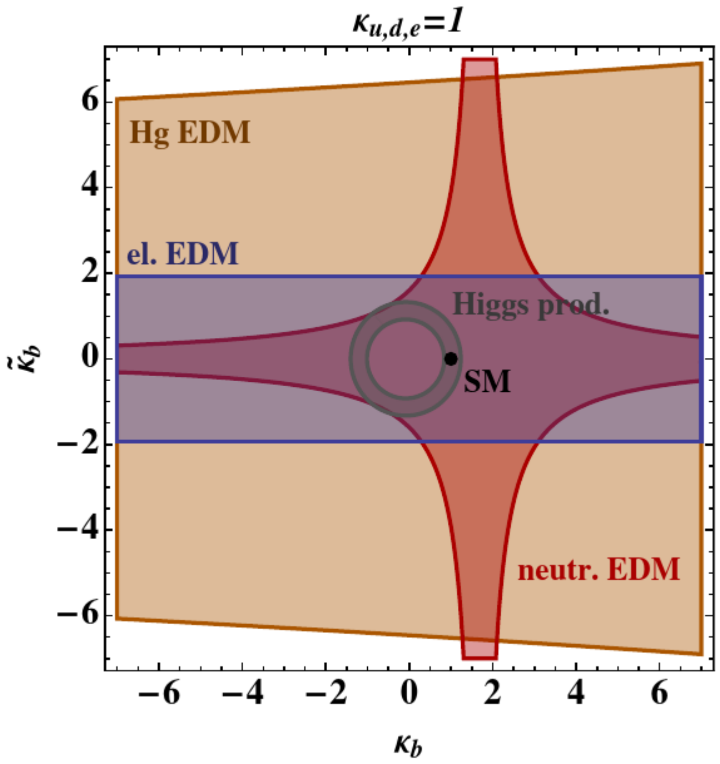
Brod, Haisch, Zupan '13

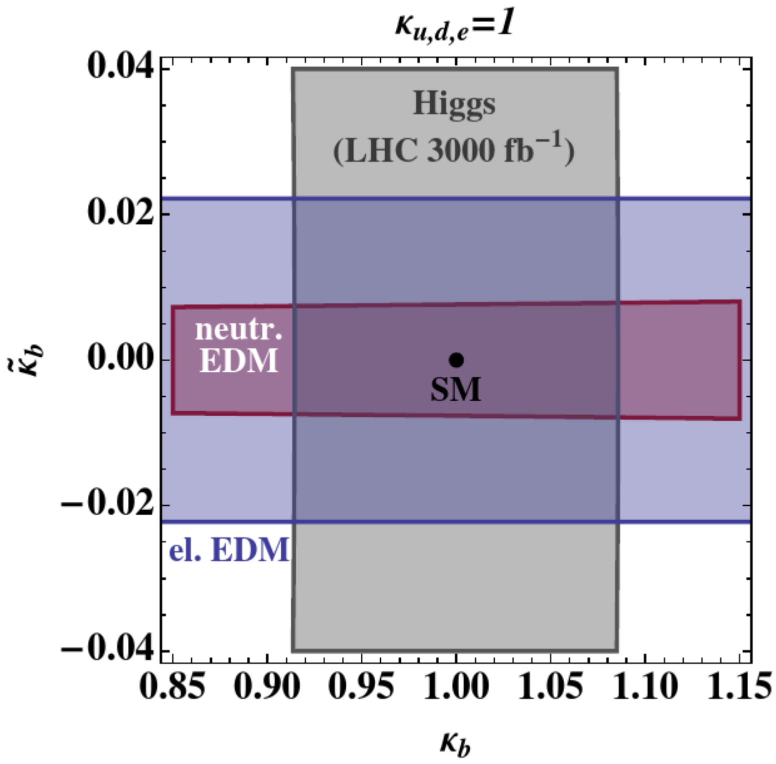


EDM & LHC limits CPV Yukawas

bottom

Brod, Haisch, Zupan '13

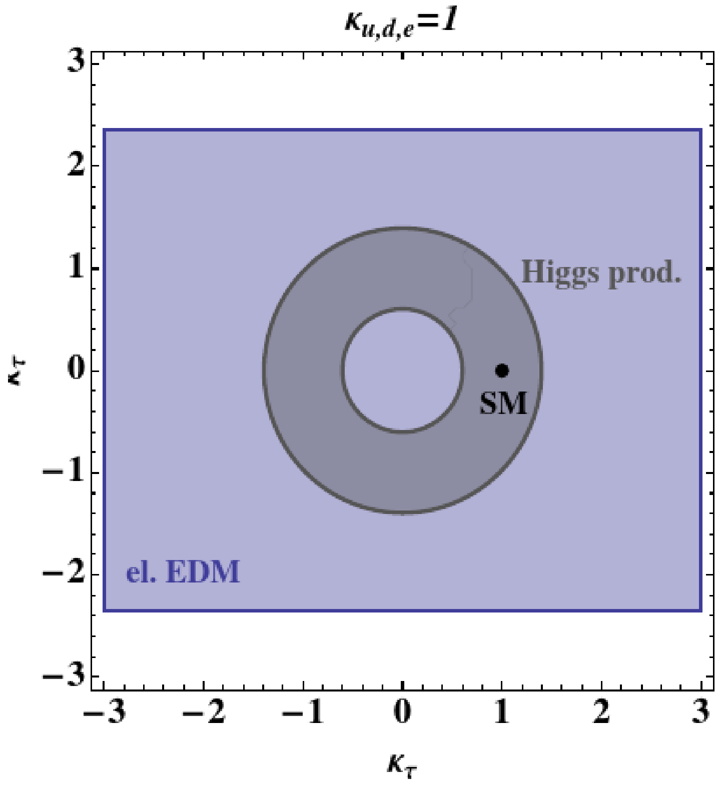


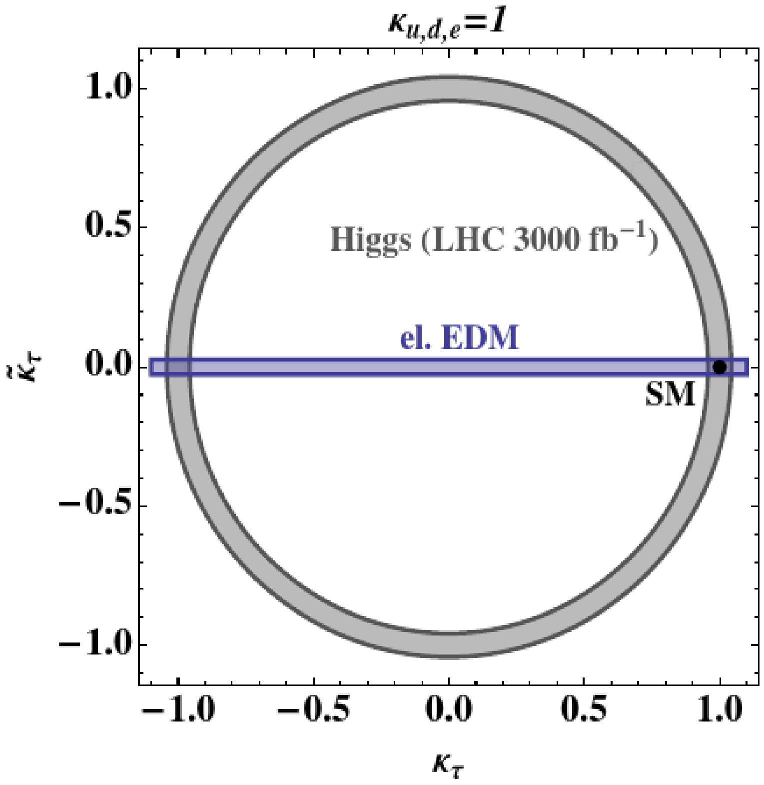


EDM & LHC limits CPV Yukawas

tau

Brod, Haisch, Zupan '13





Our Goals

EF, Losada, Nir, Viernik '19, '20 + ongoing

- Calculate baryon asymmetry Y_B from several complex Yukawas in EFT
- Confront CP violation required by BG with Higgs and EDM constraints
- Consider combination of phases
- Focus on CPV, *assume* ew phase transition can be enhanced separately

Find/exclude viable region in agreement with these 3 complementary observables

Outline

Framework

- Dim-6 EFT
- Yukawa term

Complementary probes

- EWBG
- EDM
- Higgs production and decay

Single-Yukawa modification

- 3rd generation
- muon

Combination of 2 complex Yukawas

- tau+b
- t+tau
- t+b

I. FRAMEWORK

SMEFT: dim-6 Yukawa

- Consider dim-6 Yukawa with real and imaginary part

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

cf [de Vries, Postma, van de Vies '18] where $X_R^f \equiv 0$, $X \equiv \pm i Y_f$

- Relative size of dim-6 normalized to dim-4

$$T = m_f^{(6)} / m_f^{(4)}$$

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

Our coordinates

Impact on fermion mass & Yukawa

$$m_f = \frac{Y_f v}{\sqrt{2}}\left(1 + T_R^f + iT_I^f\right), \quad \lambda_f = \frac{Y_f}{\sqrt{2}}\left(1 + 3T_R^f + 3iT_I^f\right)$$

rotate into basis where mass is real

$$m_f \overline{f_L} f_R$$

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

$$\frac{Y_f v}{\sqrt{2}}\left[1 + T_R^f + \mathcal{O}(T^{f2})\right] \qquad \frac{Y_f}{\sqrt{2}}\left[1 + 3T_R^f + 2iT_I^f + \mathcal{O}(T^{f2})\right].$$

T_R, T_I, y

Relation between SM mass and Yukawa fixes y (a priori free coefficient of dim-4 term)

$$1 = (y/y^{\mathrm{SM}})^2 \left[(1+T_R)^2 + T_I^2\right]$$

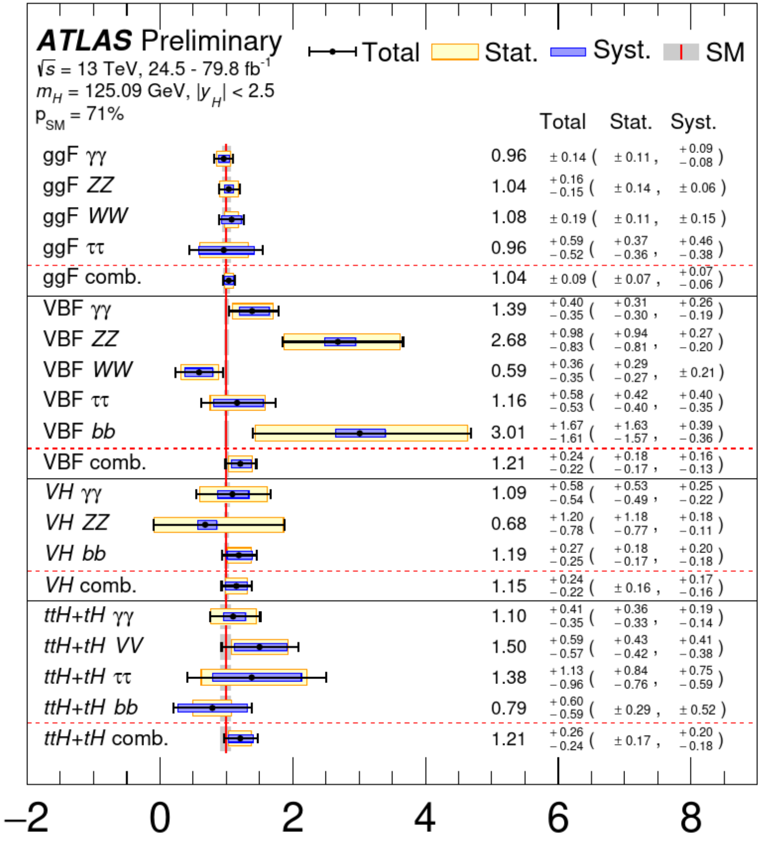
→ 2 free parameter per fermion: T_R , T_I

Modification of each vertex w.r.t. SM

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

II. HIGGS, EDM, EWBG OBSERVABLES

Higgs signal strengths



$$\mu_{if} \equiv \frac{\sigma_i(pp \to h) \cdot \mathrm{BR}(h \to \bar{f}f)}{[\sigma_i(pp \to h) \cdot \mathrm{BR}(h \to \bar{f}f)]_{\mathrm{SM}}}$$

decay $\Gamma(h \to f\bar{f})/[\Gamma(h \to f\bar{f})]^{\mathrm{SM}} = r_f$

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

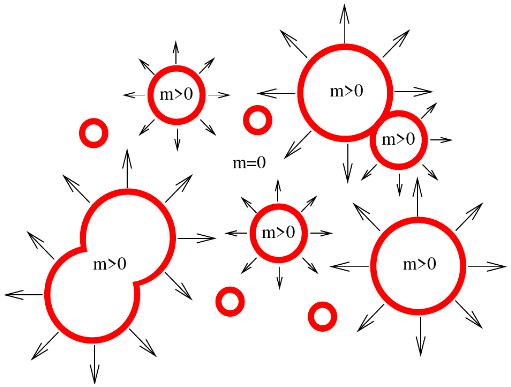
Total width $\Gamma_h/\Gamma_h^{\mathrm{SM}} = 1 + \mathrm{BR}_f^{\mathrm{SM}}(r_f - 1)$

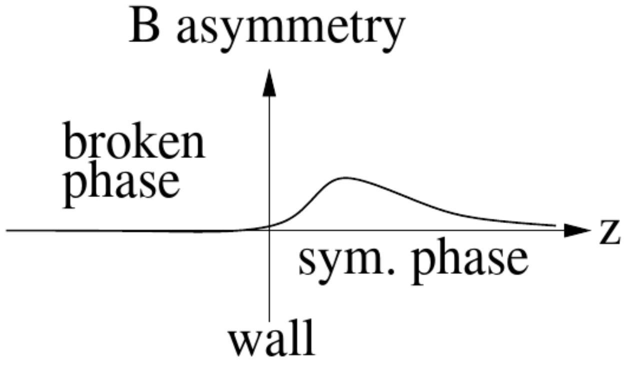
b most relevant

⇨ circle in (T_R^f, T_I^f)-plane

Electroweak baryogenesis

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





Approximations
- vev-insertion
- thin wall
- diffusion

Lots of literature, e.g.
Joyce, Prokopec, Turok '95; Morissey, Ramsey-Musolf '12; White '16; de Vries, Postma, van de Vis, White '16; de Vries, Postma, van de Vis '18; ...

Rates and transport equations

Transport equations for each fermion and Higgs, set coupled differential equations

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

relaxation — Yukawa — Strong sphaleron — weak — source

$$\Gamma_M \to \left[\frac{(1+r^2_{N0}T^f_R)^2 + r^2_{N0}T^{f2}_I}{(1+T^f_R)^2 + T^{f2}_I}\right]\Gamma_M\,,$$

$$\Gamma_Y \to \left[\frac{(1+3r^2_{N0}T^f_R)^2 + (3r^2_{N0}T^f_I)^2}{(1+T^f_R)^2 + T^{f2}_I}\right]\Gamma_Y$$

$$S_f \propto \mathcal{I}m(m^*_f m'_f) \propto Y^2_f T^f_I$$

Solve for left-handed particle density or directly baryon density

Transport equations

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

Diffusion approximation

$$\partial t = -\Gamma^t_M \mu^t_M - \Gamma^t_Y \mu^t_Y + \Gamma_{ss}\mu_{ss} + S_t$$

$$\partial b = -\Gamma^b_M \mu^b_M - \Gamma^b_Y \mu^b_Y + \Gamma_{ss}\mu_{ss} + S_b$$

$$\partial q = -\partial t - \partial b$$

$$\partial \tau = -\Gamma^\tau_M \mu^\tau_M - \Gamma^\tau_Y \mu^\tau_Y + S_\tau$$

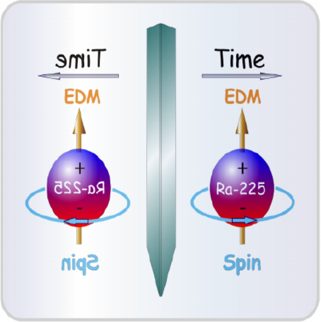
$$\partial l = -\partial \tau$$

$$\partial h = +\Gamma^t_Y \mu^t_Y - \Gamma^b_Y \mu^b_Y - \Gamma^\tau_Y \mu^\tau_Y$$

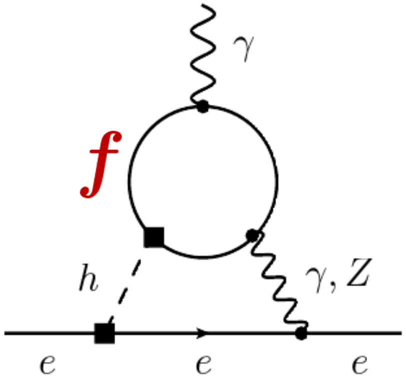
$$\partial u = +\Gamma_{ss}\mu_{ss} \,.$$

Electron's Electric Dipole Moment

[Hewett, Weerts et al '12]



EDM violates $\mathcal{T}$ and $\mathcal{P}$
$\Rightarrow \not{\mathcal{CP}}$



ACME [Nature '18]:

$$d_e \leq 1.1 \times 10^{-29}\, e\,\mathrm{cm} \text{ at } 90\% \text{ CL}$$

Using [Panico, Pomarol, Riembau '18],
see also [Brod, Haisch, Zupan '13], [Brod, Stamou '18],...

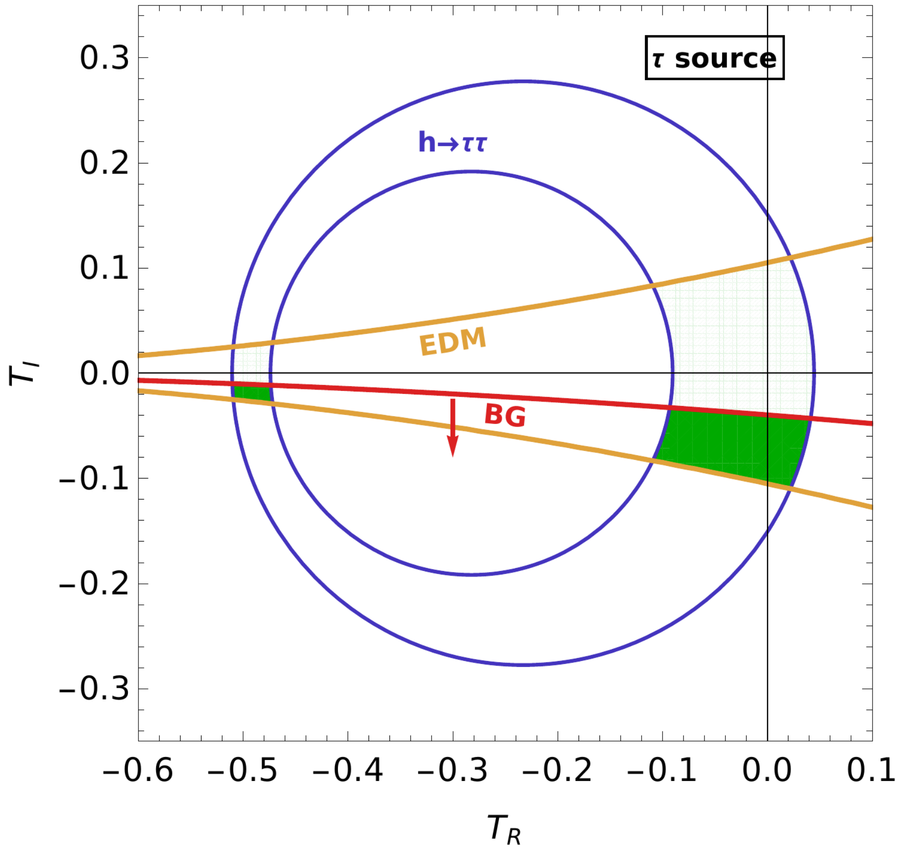
$$\frac{d_e^{(\ell)}}{e} \simeq -4Q_\ell^2 \frac{e^2}{(16\pi^2)^2} \frac{m_e m_\ell}{m_h^2} \frac{v}{\Lambda^2} \boldsymbol{X_I^\ell} \left(\frac{\pi^2}{3} + \ln^2 \frac{m_\ell^2}{m_h^2} \right), \quad \boldsymbol{\ell = \tau, \mu}$$

$$\frac{d_e^{(b)}}{e} \simeq -4N_c Q_b^2 \frac{e^2}{(16\pi^2)^2} \frac{m_e m_b}{m_h^2} \frac{v}{\Lambda^2} \boldsymbol{X_I^b} \left(\frac{\pi^2}{3} + \ln^2 \frac{m_b^2}{m_h^2} \right)$$

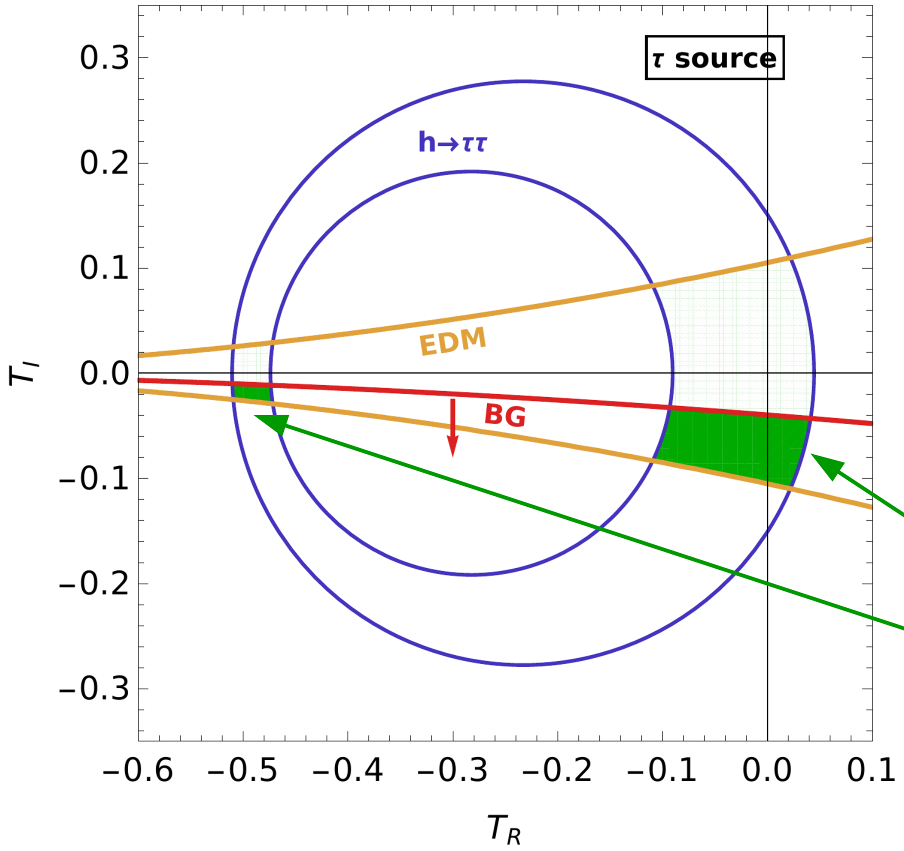
$$\frac{d_e^{(t)}}{e} \simeq -\frac{16}{3} \frac{e^2}{(16\pi^2)^2} \frac{m_e}{m_t} \frac{v}{\Lambda^2} \boldsymbol{X_I^t} \left(2 + \ln \frac{m_t^2}{m_h^2} \right)$$

III. RESULTS: Single-Yukawa modification

τ Yukawa – the winner

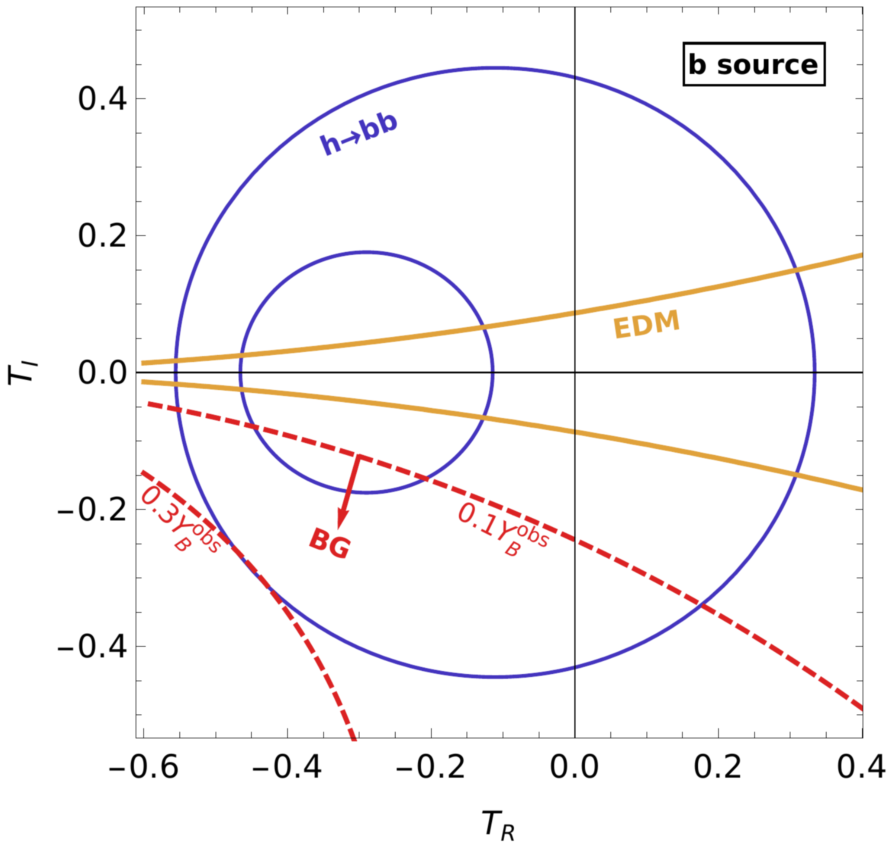


τ Yukawa – the winner

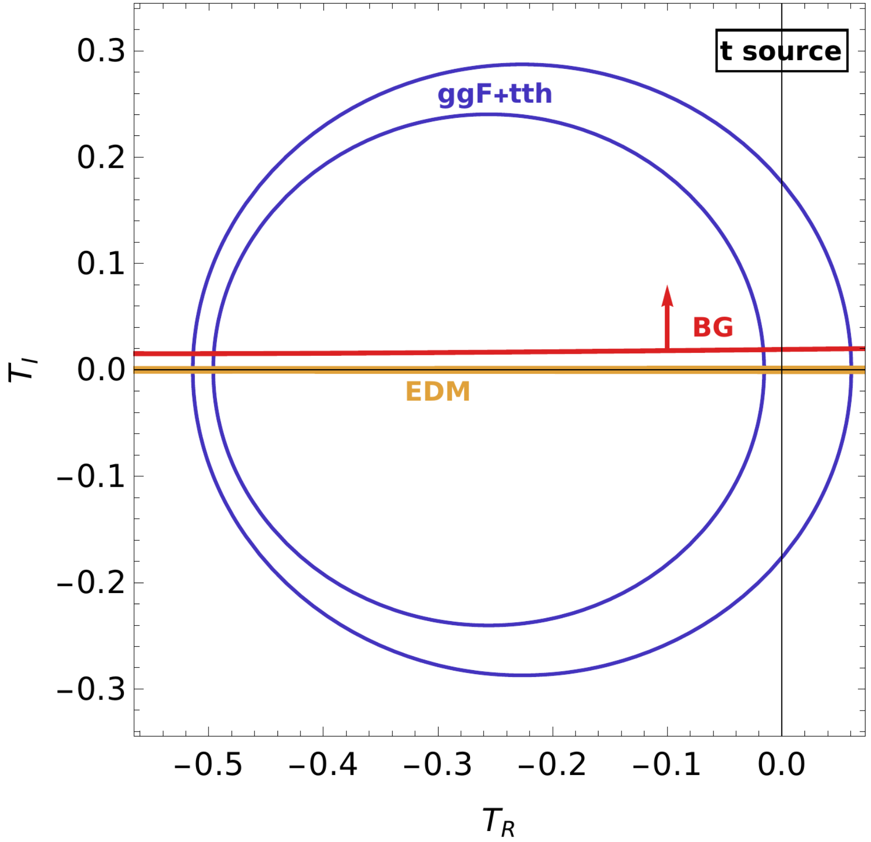


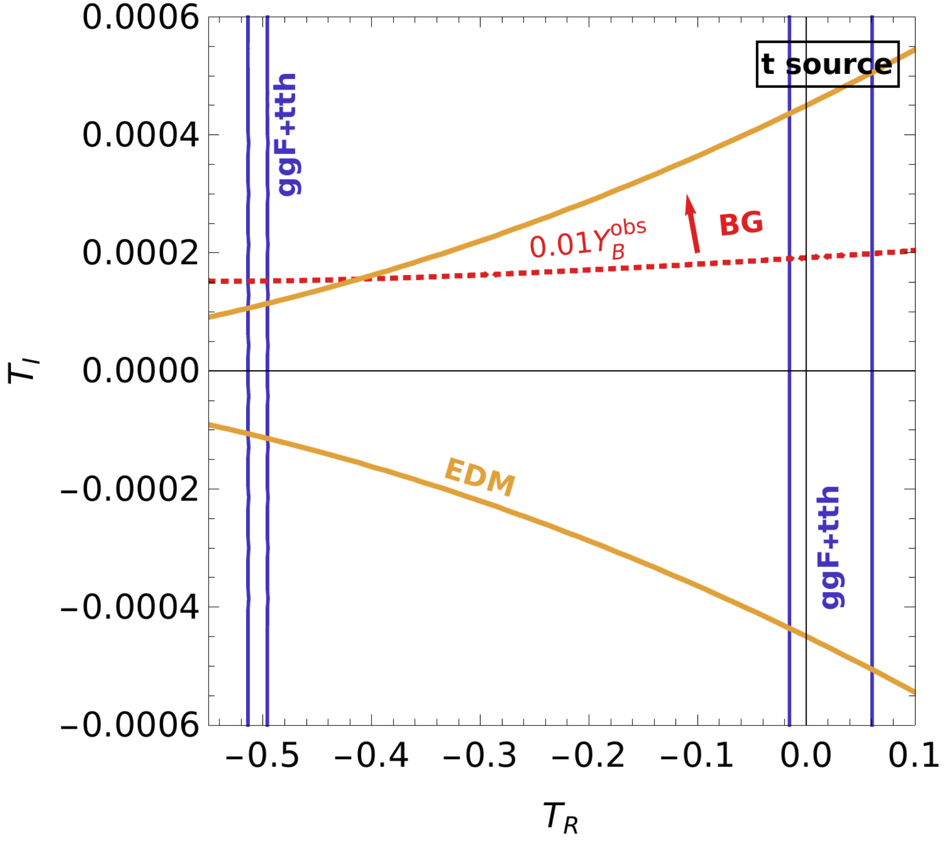
Allowed by all 3 constraints!

b Yukawa – the broad



t Yukawa – the constrained





μ Yukawa – the surprise

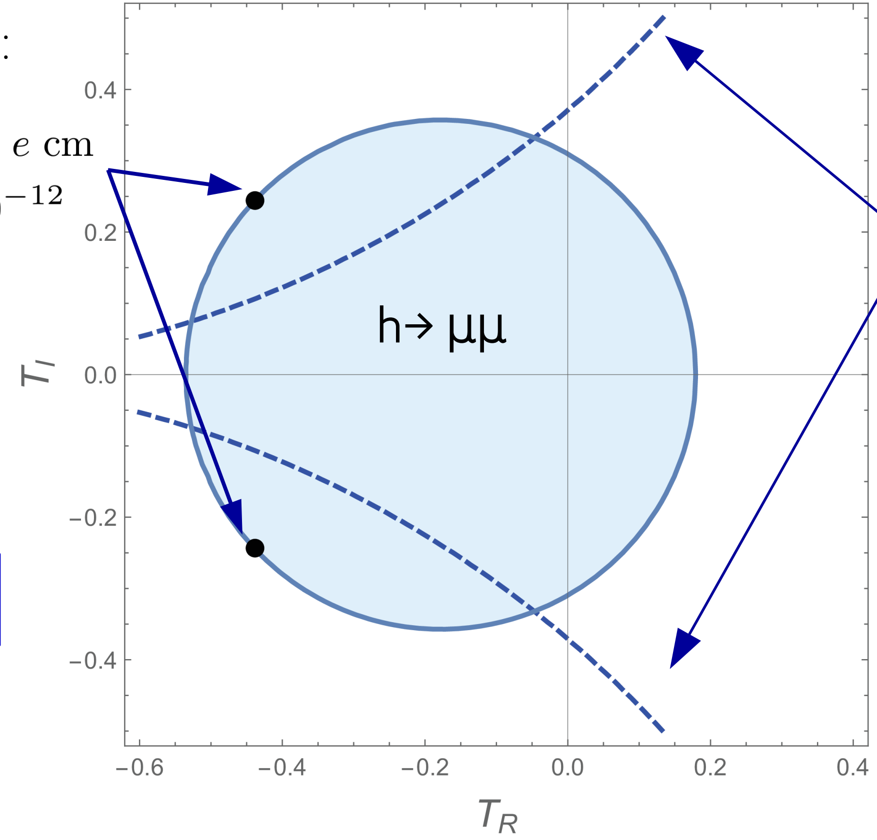
Maximal EDM, BG:

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

$|Y_B^{(\mu)}|_{\max} = 7.2 \times 10^{-12}$

Upper bound on h→ μμ:

μ_μ<1.7 (ATLAS)



contours of $|Y_B^{(\mu)}|_{\max}/2$ and $|d_e^{(\mu)}|_{\max}/2$

EWBG from μ Yukawa:
Allowed by EDM
Excluded by LHC

IV. RESULTS: Two-Yukawa combinations

Higgs production and decay

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

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

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

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

Interplay of 2 complex Yukawas in production and/or decay

EDM and BG coefficients

for $T_R = 0$

$$Y_B = 8.6 \times 10^{-11} \times (+51T_I^t - 23T_I^\tau - 0.44T_I^b - 0.13T_I^\mu)$$

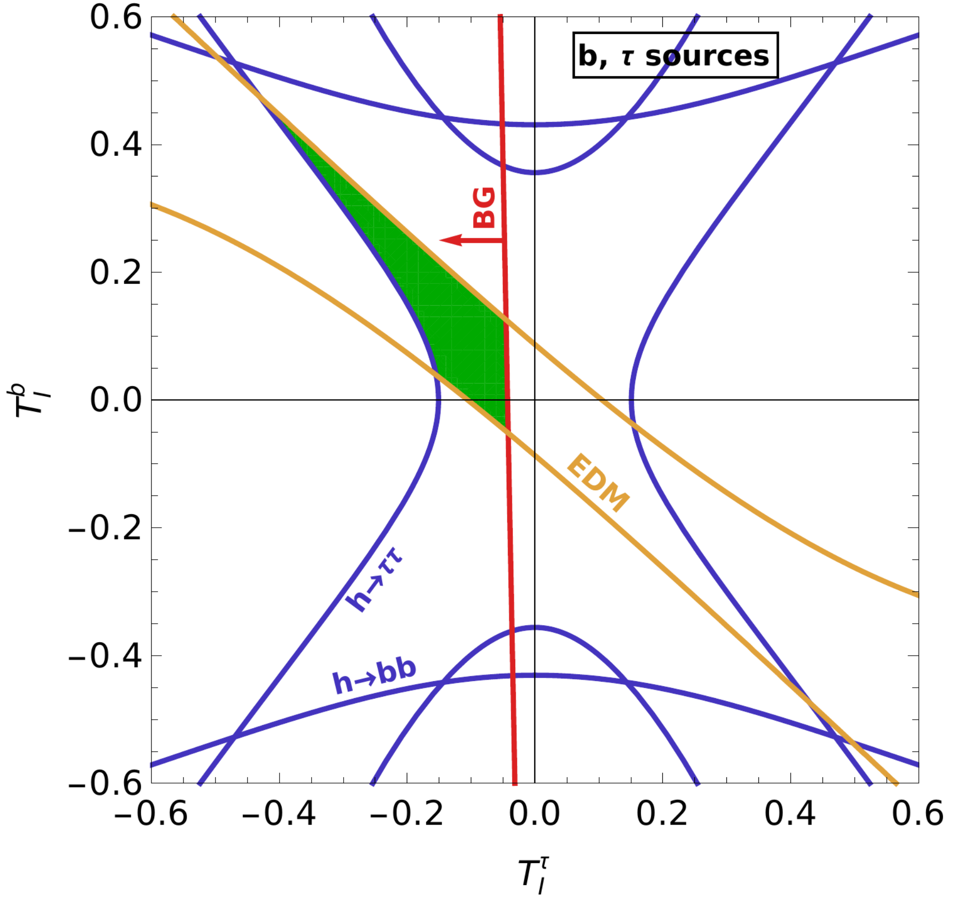
$$d_e = 1.1 \times 10^{-29}\ e\ \text{cm} \times (2223T_I^t + 9.6T_I^\tau + 11.6T_I^b + 0.09T_I^\mu)$$

Different relative contribution of the 4 species to BG or EDM

Cancellations in EDM + enhancement of baryogenesis?

τ and b

$T_R^f = 0$

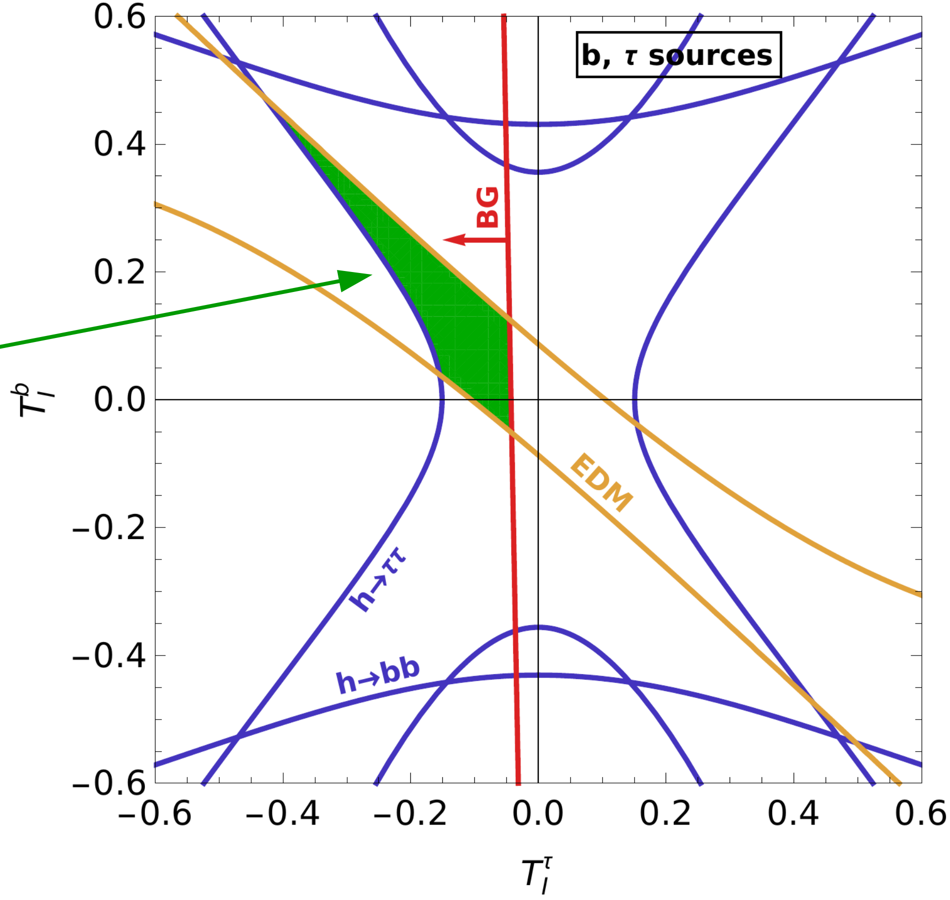


b, τ sources
BG
EDM
h→ττ
h→bb
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
T_I^b
T_I^τ

τ and b

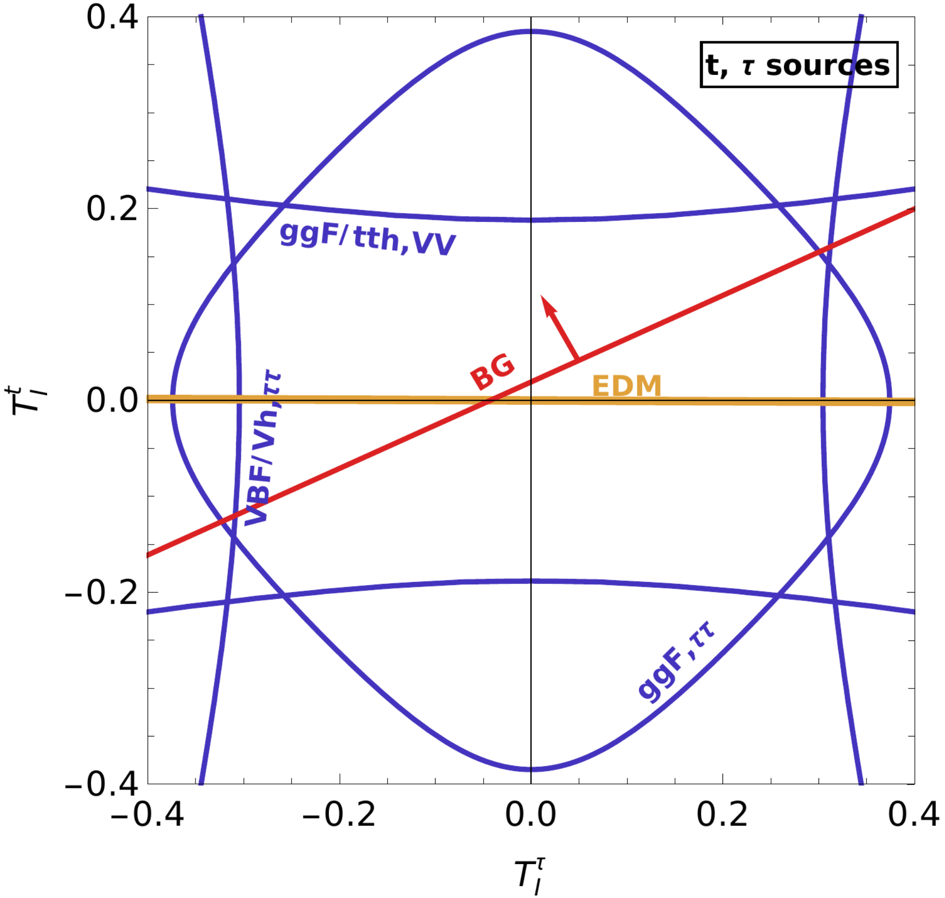
$T_R^f = 0$

Allowed by all 3 constraints!



t and τ

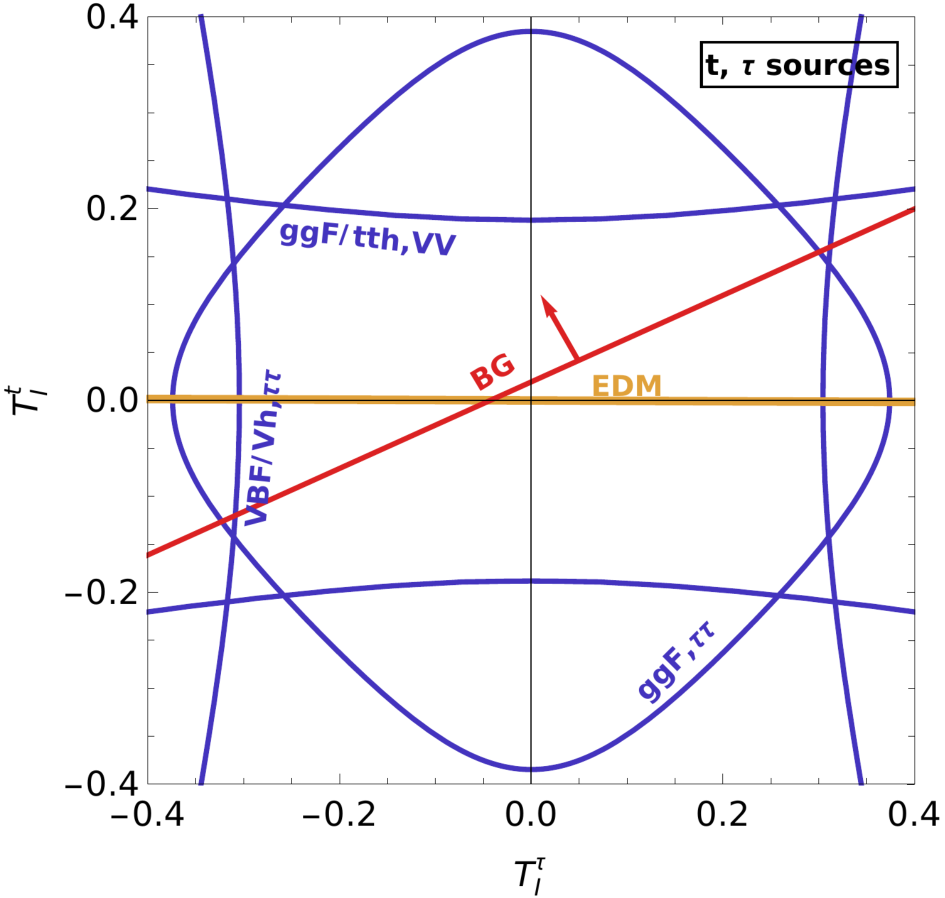
$T_R^f = 0$



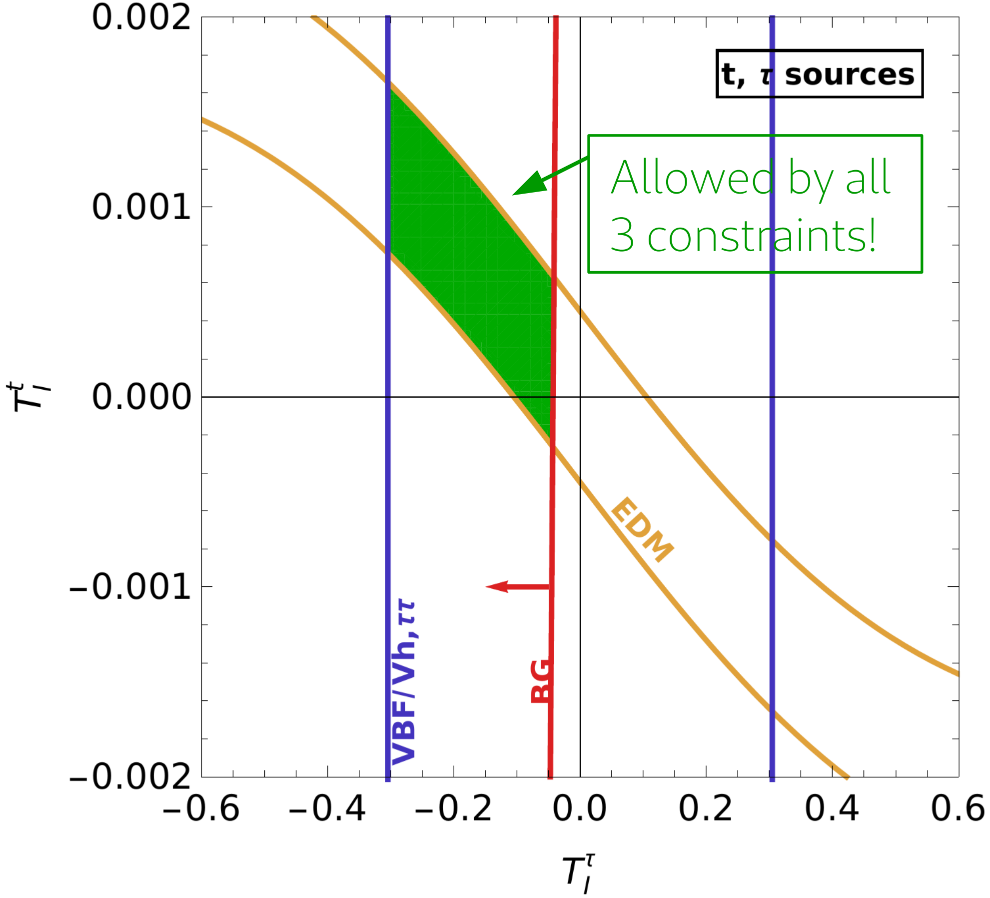
T_i^t severly constrained by EDM

t and τ

$T_R^f = 0$



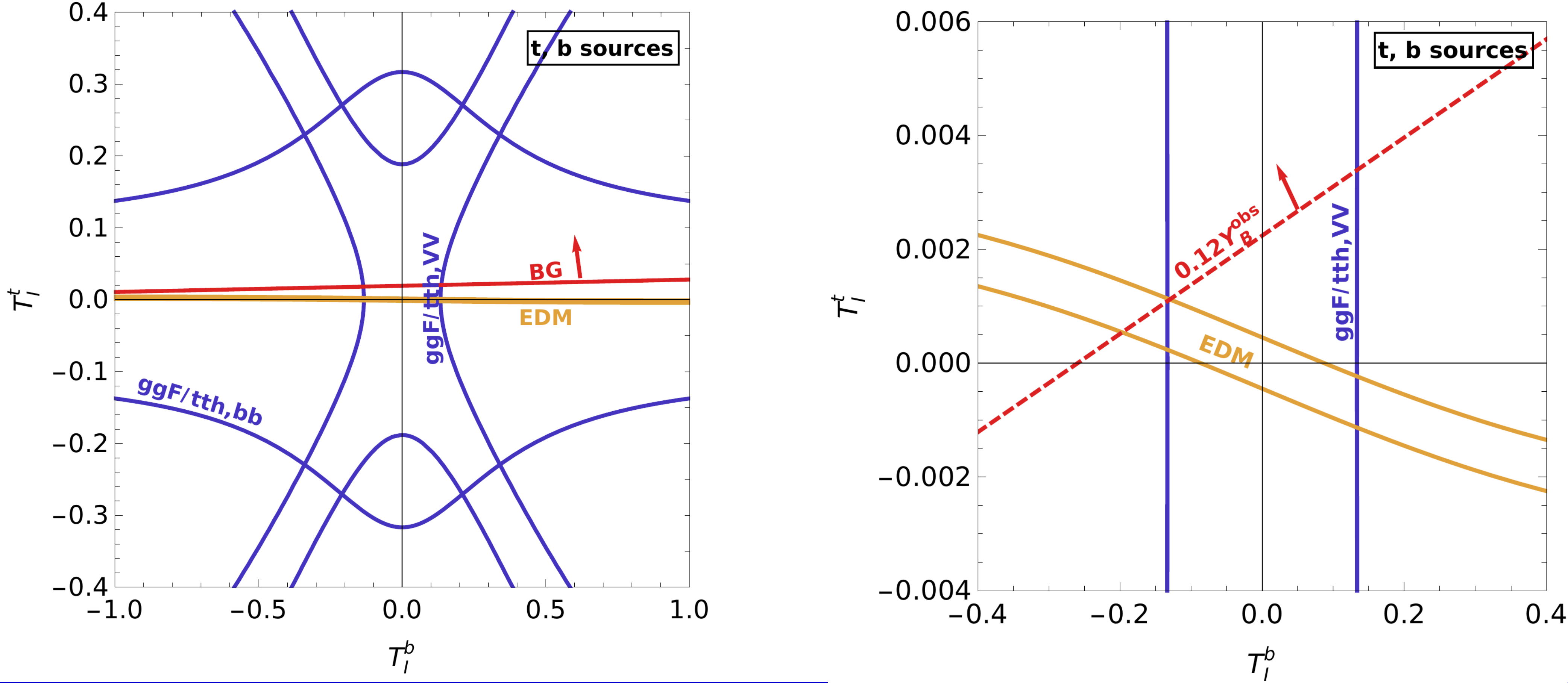
t, τ sources
ggF/tth,VV
VBF/Vh,ττ
BG
EDM
ggF,ττ
0.4
0.2
0.0
−0.2
−0.4
T_I^t
T_I^τ



t, τ sources
Allowed by all
3 constraints!
VBF/Vh,ττ
BG
EDM
0.002
0.001
0.000
−0.001
−0.002
−0.6
−0.4
−0.2
0.0
0.2
0.4
0.6
T_I^t
T_I^τ

t and b: not sufficient

$T_R^f = 0$



Cut-off scales $\Lambda/\sqrt{X_{R,I}}$

Minimal scales for maximally **allowed** T (collider, EDM)

- τ: 2.4 TeV, 3.1 TeV
- b: 1.5 TeV, 1.7 TeV
- τ: 247 GeV, 318 GeV (only v at T_R=-0.5, but larger at T~0);
  - 8.7 TeV from EDM
- μ: 10 TeV, 12 TeV

Maximal scales for minimally **required** T_I (EWBG)

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

Observations: 1 flavor

tau: Can account for observed B asymmetry!

- Robust: reaches **2.4** times observed Y_B
  - no strong sphaleron washout
  - large diffusion
  - still sizeable Yukawa

  } advantages

bottom

- Large BR(h→ bb) broadens LHC region
- Reaches only **4%** of observed Y_B

top

- Severely constrained by EDM
- Reaches only **2%** of observed Y_B

muon

- Could explain Y_B within EDM limit
- But ruled out by LHC h→ μμ
- Reaches **16%** of observed Y_B

Observations: 2 flavors

τ+b

- maximal

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

τ+t

- maximal

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

t+b

- Cannot account for BG together
- Reach only **12%** of observed Y_B

What if eEDM=0 and Higgs rates SM-like?

- τ+b with nonzero T_R, T_I:
  - $Y_B^{b+\tau,\max}(d_e = 0, \mu_b = \mu_\tau = 1) = 10.25 Y_B^{\text{obs}}$
  - EWBG possible with 0 CPV signals!

Conclusions and future thoughts

- **Complementarity** of EDM, BG and Higgs physics
- LHC can constrain cosmology
- Importance of taking also **real parts** of dim-6 terms
- **Cancellations and enhancements** with 2 fermions

Conclusions and future thoughts

- **Complementarity** of EDM, BG and Higgs physics
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- Importance of taking also **real parts** of dim-6 terms
- **Cancellations and enhancements** with 2 fermions

- EW phase transition
- Concrete models
- Future collider and EDM sensitivities
  - CPV observables, e.g.in $h \to \tau\tau$ ATLAS PUB-2019-008

THANK YOU!

APPENDIX

2-step: baryon density from L density

$$n_b''(z) - \frac{v_w}{D_q} n_b'(z) = \frac{\Gamma_{ws}(z)}{D_q}\left(\mathcal{R} n_b(z) + \frac{3}{2} n_L(z)\right) \equiv \frac{\Gamma_{ws}(z)}{D_q}\mathcal{R} n_b + f(z)$$

$$Y_B = \frac{n_b(z>0)}{s} = \frac{A_1}{s} = \frac{1}{s}\left(1 - \frac{\alpha_-}{\alpha_+}\right) B_1 = \frac{k}{D_q \alpha_+ s} B_1$$
$$= \frac{3\Gamma_{ws}}{2 D_q \alpha_+ s}\int_0^{-\infty} e^{-\alpha_- x} n_L(x) dx \,.$$

Chemical potentials

$$\mu_M^t = \frac{t}{k_t} - \frac{q}{k_q}\,, \qquad \mu_M^b = \frac{b}{k_b} - \frac{q}{k_q}\,, \qquad \mu_M^\tau = \frac{\tau}{k_\tau} - \frac{l}{k_l}\,,$$

$$\mu_Y^t = \frac{t}{k_t} - \frac{q}{k_q} - \frac{h}{k_h}\,, \qquad \mu_Y^b = \frac{b}{k_b} - \frac{q}{k_q} + \frac{h}{k_h}\,, \qquad \mu_Y^\tau = \frac{\tau}{k_\tau} - \frac{l}{k_l} + \frac{h}{k_h}\,,$$

$$\mu_{ss} = \sum_{i=1}^{3} \frac{2q_i}{k_{q_i}} - \frac{u_i}{k_{u_i}} - \frac{d_i}{k_{d_i}}\,.$$

Matrix formalism: o.d.e. 1st order

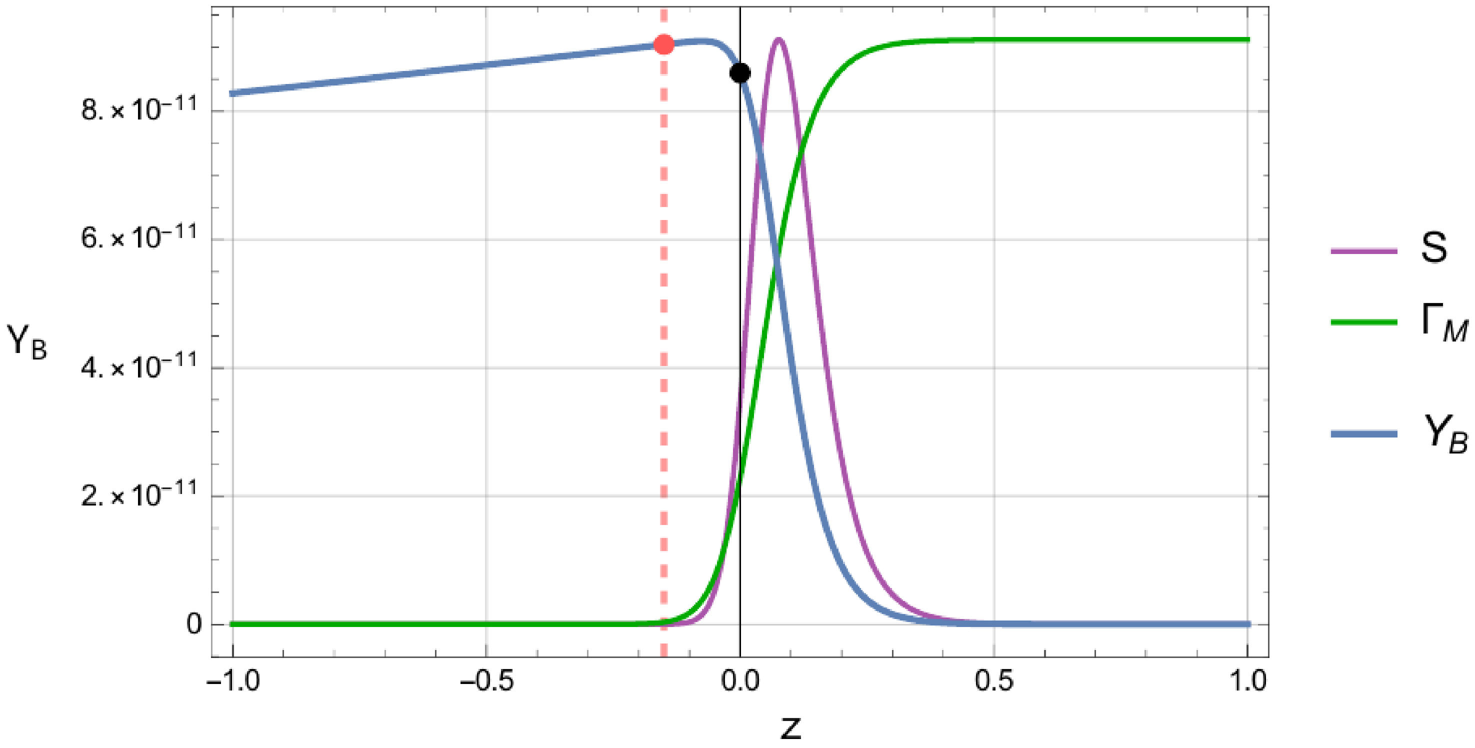
$$
\begin{pmatrix} t' \\ b' \\ \vdots \\ g_t' \\ g_b' \\ \vdots \end{pmatrix}
-
\begin{pmatrix}
0 & & & 1 & & \\
& 0 & & & 1 & \\
& & \ddots & & & \ddots \\
& & & \frac{v_w}{D_t} & & \\
& & & & \frac{v_w}{D_b} & \\
& & & & & \ddots
\end{pmatrix}
\begin{pmatrix} t \\ b \\ \vdots \\ g_t \\ g_b \\ \vdots \end{pmatrix}
=
\begin{pmatrix}
0 & & & & \\
& \ddots & & & \\
\frac{\Gamma_t}{D_t k_t} & & & & \\
& \frac{\Gamma_b}{D_b k_b} & & \ddots & \\
& & \ddots & & 0
\end{pmatrix}
\begin{pmatrix} t \\ b \\ \vdots \\ g_t \\ g_b \\ \vdots \end{pmatrix}
+
\begin{pmatrix} 0 \\ 0 \\ \vdots \\ S_t/D_t \\ S_b/D_b \\ \vdots \end{pmatrix}
$$

$$
\Longleftrightarrow \quad \bar{\chi}' - K\bar{\chi} = \bar{S}\,, \qquad\qquad K \equiv \begin{pmatrix} 0 & I_N \\ \Gamma & V \end{pmatrix}.
$$

Particle dynamics

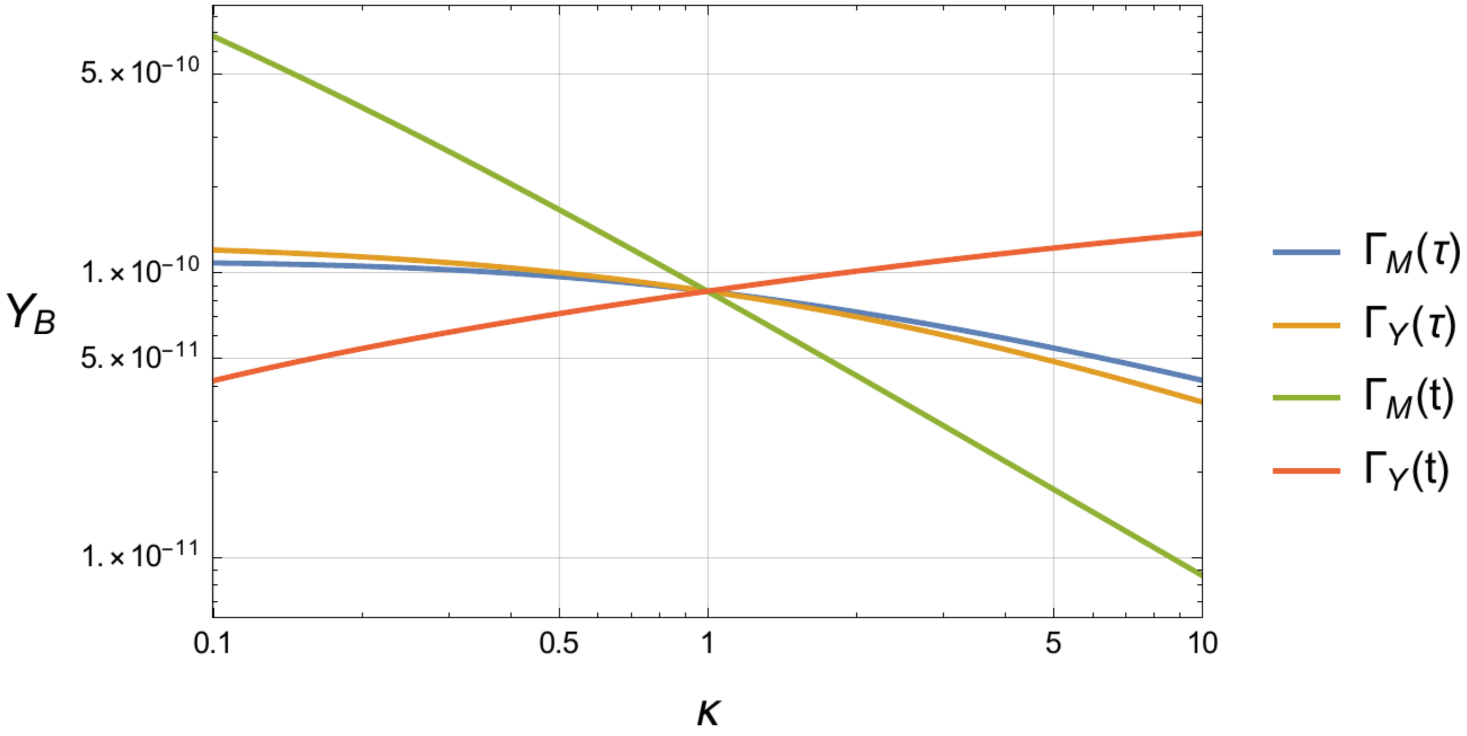
- CPV interactions across the expanding bubble wall **generate a chiral asymmetry**
- CPC interactions **wash out** the generated asymmetry
- Strong sphaleron process produces further washout in the quark sector
- Some of the remaining asymmetry diffuses into the symmetric phase; more efficient for leptons than quarks.
- Weak sphaleron process is efficient only in the symmetric phase, acting on left-handed multiplets and changing baryon number.
- Finally, the bubble wall catches up and freezes in the resulting baryon number density in the broken phase.

Thin-wall approximation



Uncertainty of Y_B from input rates

$$\Gamma^f_{M/Y} \to \kappa^f_{M/Y} \Gamma^f_{M/Y}$$



LHC results

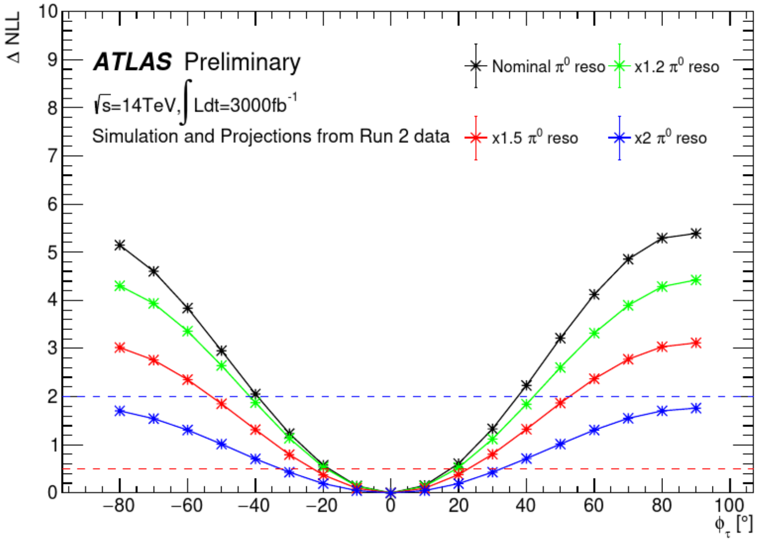
channel	experiment	$\sqrt{s}$ / TeV	$\mathscr{L}$ / fb^{-1}	comment	μ	Ref
$h \to \tau^+\tau^-$	ATLAS+CMS	7+8	$5+20$		$1.11^{+0.24}_{-0.22}$	[16]
	ATLAS	13	36.1	ggF, VBF	$1.09^{+0.35}_{-0.30}$	[17]
	CMS	13	77	ggF, $\bar{b}b$, VBF, Vh	0.75 ± 0.17	[18]
	ATLAS+CMS	7+8+13		all prod., priv. comb.	0.91 ± 0.13	[16–18]
$h \to \mu^+\mu^-$	ATLAS	13	139	upper bound at 95% C. L.	< 1.7	[19]
	CMS	13	35.9	upper bound at 95% C. L.	< 2.9	[20]
$h \to \bar{b}b$	ATLAS	13	79.8	VBF+VH	1.23 ± 0.26	[15]
				$t\bar{t}h + th$	$0.79^{+0.60}_{-0.59}$	
	CMS	7+8+13	41.3	VH (0-2ℓ, 2 b-tags+jets)	1.01 ± 0.22	[21]
				all prod.	1.04 ± 0.2	
	ATLAS+CMS	7+8+13	≤ 79.8	VH, priv. comb.	0.98 ± 0.15	[14, 21]
				all prod., priv. comb.	1.02 ± 0.14	

LHC results - top

channel	experiment	$\sqrt{s}$/ TeV	$\mathscr{L}$/ fb^{-1}	comment	μ	Ref
ggF	ATLAS	13	≤ 79.8	$H \to \gamma\gamma$	0.96 ± 0.14	[15]
				$H \to \tau\tau$	$0.96^{+0.59}_{-0.52}$	
				all decays, fixed to SM	1.04 ± 0.09	
	CMS	13	35.9	$H \to \gamma\gamma$	$1.16^{+0.30}_{-0.25}$	[22]
				$H \to \tau\tau$	$1.05^{+0.75}_{-0.67}$	
				all decays, fixed to SM	$1.22^{+0.20}_{-0.18}$	
	ATLAS+CMS	13	$\leq$	$H \to \gamma\gamma$, priv. comb.	1.00 ± 0.12	[15, 22]
				$H \to \tau\tau$, priv. comb.	0.99 ± 0.44	
				all decays SM, priv. comb.	1.07 ± 0.08	
$\bar{t}th + th$	ATLAS	13	≤ 79.8	$H \to \gamma\gamma$	$1.1^{+0.41}_{-0.35}$	[15]
				$H \to \tau\tau$	$1.38^{+1.13}_{-0.96}$	
				$H \to \bar{b}b$	$0.79^{+0.60}_{-0.59}$	
				all decays, fixed to SM	$1.21^{+0.26}_{-0.24}$	
	CMS	13	35.9	$H \to \gamma\gamma$	$2.18^{+1.25}_{-1.06}$	[22]
				$H \to \tau\tau$	$0.23^{+1.46}_{-1.24}$	
				$H \to \bar{b}b$	$0.91^{+0.64}_{-0.61}$	
				all decays, fixed to SM	$1.18^{+0.43}_{-0.38}$	
	ATLAS+CMS	13	$\leq$	$H \to \gamma\gamma$, priv. comb.	1.21 ± 0.36	[15, 22]
				$H \to \tau\tau$, priv. comb.	0.95 ± 0.83	
				$H \to \bar{b}b$, priv. comb.	0.87 ± 0.43	
				all decays SM, priv. comb.	1.20 ± 0.21	
ggF+$\bar{t}th + \bar{t}H$	ATLAS+CMS	13		all decays SM, priv. comb.	1.09 ± 0.08	
$h \to \gamma\gamma$	ATLAS		138	tth	$1.38^{+0.41}_{-0.36}$	[23, 24]
	CMS		77.4		$1.7^{+0.6}_{-0.5}$	[23, 25]
	ATLAS		≤ 79.8	priv. comb. of all prod	1.02 ± 0.12	[15]
	CMS		35.9		$1.2^{+0.25}_{-0.20}$	[22]

CPV ATLAS h→ ττ: Prospects for HL

This note presents a study for the prospective measurement of the $\mathcal{CP}$ quantum number of the Higgs boson coupling to τ leptons with 3000 fb^{-1} of proton–proton collisions at $\sqrt{s} = 14$ TeV using the ATLAS detector at the HL-LHC. Only $H \to \tau\tau$ events where both τ leptons decay via the $\tau^{\pm} \to \rho^{\pm}\nu_{\tau} \to \pi^0\pi^{\pm}\nu_{\tau}$ chain are analysed and the acoplanarity angle $\varphi^{*}_{\mathcal{CP}}$, the angle between the planes spanned by the pion pairs, is used to determine the $\mathcal{CP}$-mixing angle. It is shown that considering only statistical uncertainties, a pseudoscalar Higgs boson can be excluded at 95% confidence level. The $\mathcal{CP}$-mixing angle can be measured with a statistical precision ranging between ±18° and ±33°, depending on the precision of the π^0 reconstruction



$$\mathcal{L} = g_{\tau\tau}(\cos(\phi_\tau)\overline{\tau}\tau + \sin(\phi_\tau)\overline{\tau}i\gamma_5\tau)h$$

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