Searching for a flavor changing decay $t \to c\, h$ at the LHC

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Based on:

Kai-Feng Chen, Wei-Shu Hou, Chung Kao, and MK, arXiv:1304.8037

August 18, Summer Institute 2013 @ Jirisan National Park, Korea

Why t → ch?

- top and Higgs are two most massive particles ever discovered
- it is of great interest to see a link between these two particles
- in SM, t → c h is induced at 1-loop and is highly suppressed due to GIM & CKM:

$$\mathcal{B}(t \to ch) \simeq 3 \times 10^{-15}$$

Eilam et al., PRD'91; Mele et al., PLB'98; Aguilar-Saavedra '04

- current experimental data is sensitive to 1% level (discussed later)
- so, t → c h is a good place to see New Physics effects
- this talk: general two Higgs doublet model (2HDM-III)

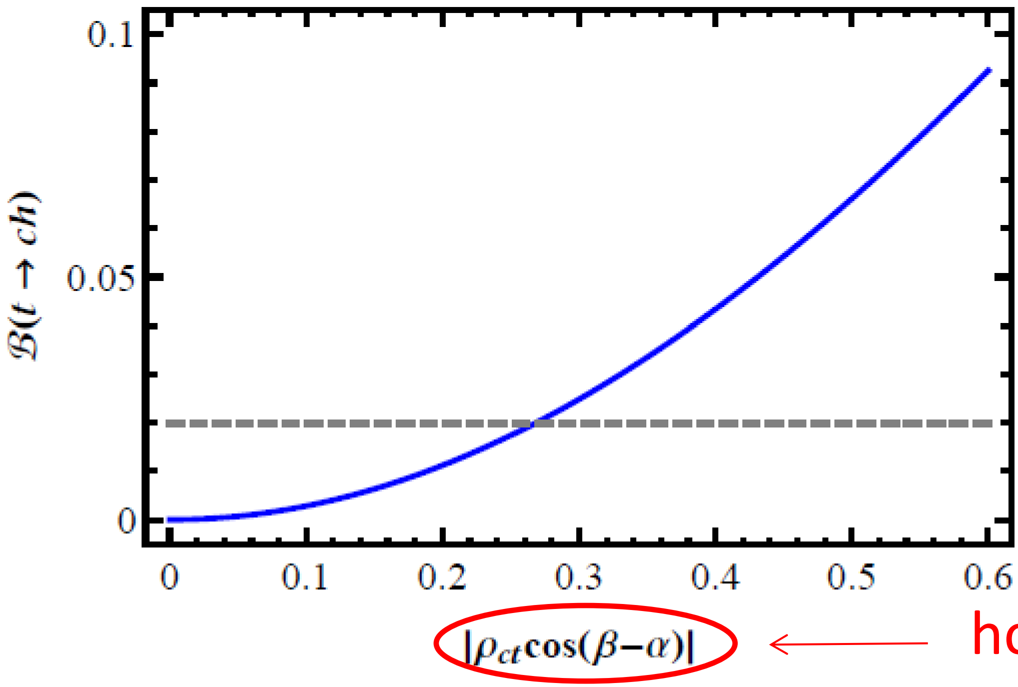
t-c-h coupling in 2HDM-III

$$\rho_{ct}\cos(\beta-\alpha)\bar{c}th + \mathrm{H.c.}$$ (tree-level)

extra Yukawa coupling (ρ_{ct})

mixing in CP-even Higgs sector ($\cos(\beta-\alpha)$)
(following type-II convention)

* forbidden in 2HDM with Natural Flavor Conservation (e.g., type-II 2HDM),
  hence, great impact if discovered [Glashow and Weinberg]



how large can this be?

A motivation for a large ρ_{ct}: BaBar "anomaly" for $B \rightarrow D\tau\nu$ and $B \rightarrow D^{(*)}\tau\nu$

BaBar, PRL '12

$$\mathcal{R}(D^{(*)}) = \frac{\Gamma(\bar{B} \to D^{(*)}\tau^-\bar{\nu})}{\Gamma(\bar{B} \to D^{(*)}\ell^-\bar{\nu})} \quad \ell = e \text{ or } \mu$$

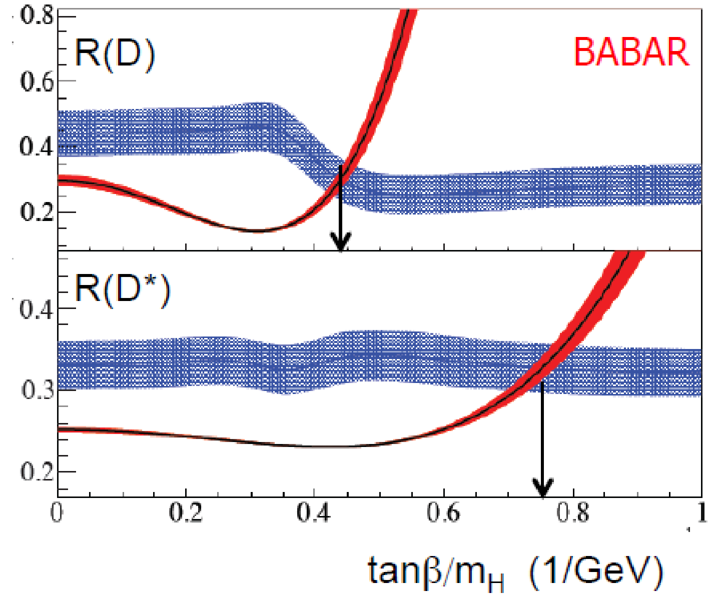
- 3.4σ (combo) deviation from SM

	R(D)	R(D*)
BABAR	0.440 ± 0.071	0.332 ± 0.029
SM	0.297 ± 0.017	0.252 ± 0.003
Difference	2.0 σ	2.7 σ

- Type-II 2HDM can not explain R(D) and R(D*) simultaneously

$$\tan\beta/m_{H^+} = 0.44 \pm 0.02 \quad \text{for } R(D)$$
$$\tan\beta/m_{H^+} = 0.75 \pm 0.04 \quad \text{for } R(D^*)$$

→ **2HDM-II is excluded with 99.8% C.L.**!



- **2HDM-III can explain the "anomaly"**

Fajfer, Kamenik, Nisandzic, Zupan, PRL'12; Crivellin, Greub, Kokulu, PRD'12

Explain BaBar anomaly by 2HDM-III

- 2HDM-III Yukawa interactions

notation follows Mahmoudi and Stal, PRD'10

$$-\frac{1}{\sqrt{2}}\sum_{f=}^{u,\,d,\,\ell}\bar{f}\left[\left(\kappa^f s_{\beta-\alpha}+\rho^f c_{\beta-\alpha}\right)h^0\right.$$

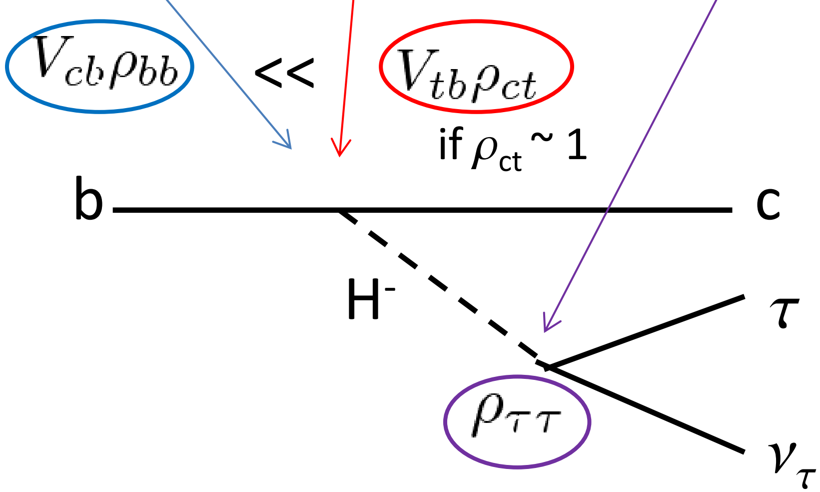
: 126 GeV Higgs

$$\left.+\left(\kappa^f c_{\beta-\alpha}-\rho^f s_{\beta-\alpha}\right)H^0-i\,\mathrm{sgn}(Q_f)\rho^f\gamma_5 A^0\right]f$$

: extra neutral Higgs

$$-\left[\bar{u}\left(V\rho^d R-\rho^u V L\right)dH^+ + \bar{\nu}\rho^\ell R\ell H^+ + \mathrm{h.c.}\right]$$

: charged Higgs



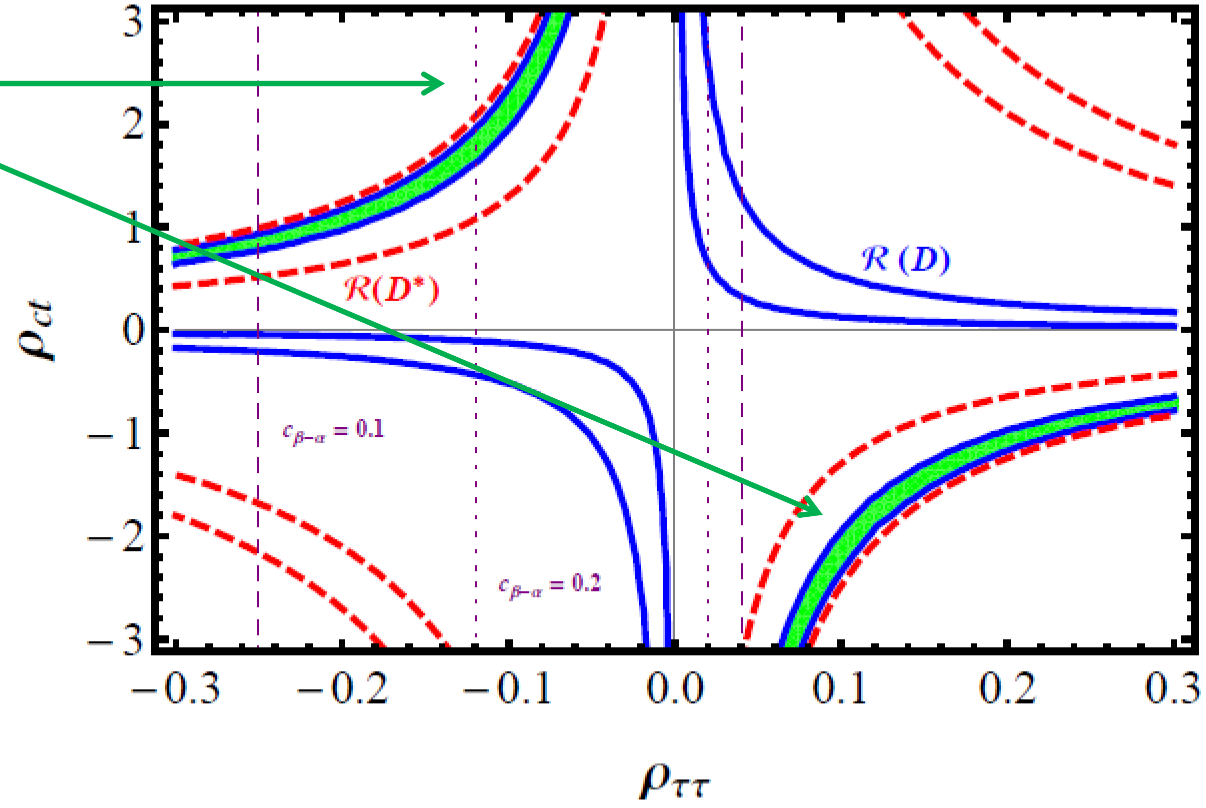
assumptions

- Hermiticity for ρ^f
- leptonic Yukawa ρ^l is diagonal
- CP-conservation in Higgs sector

* $\rho_{\tau\tau}$ affects h-τ–τ coupling, hence, constrained by h → $\tau\tau$ data

Constraint by data (m_{H^+} = 300 GeV)

1 σ allowed region by R(D) and R(D*)



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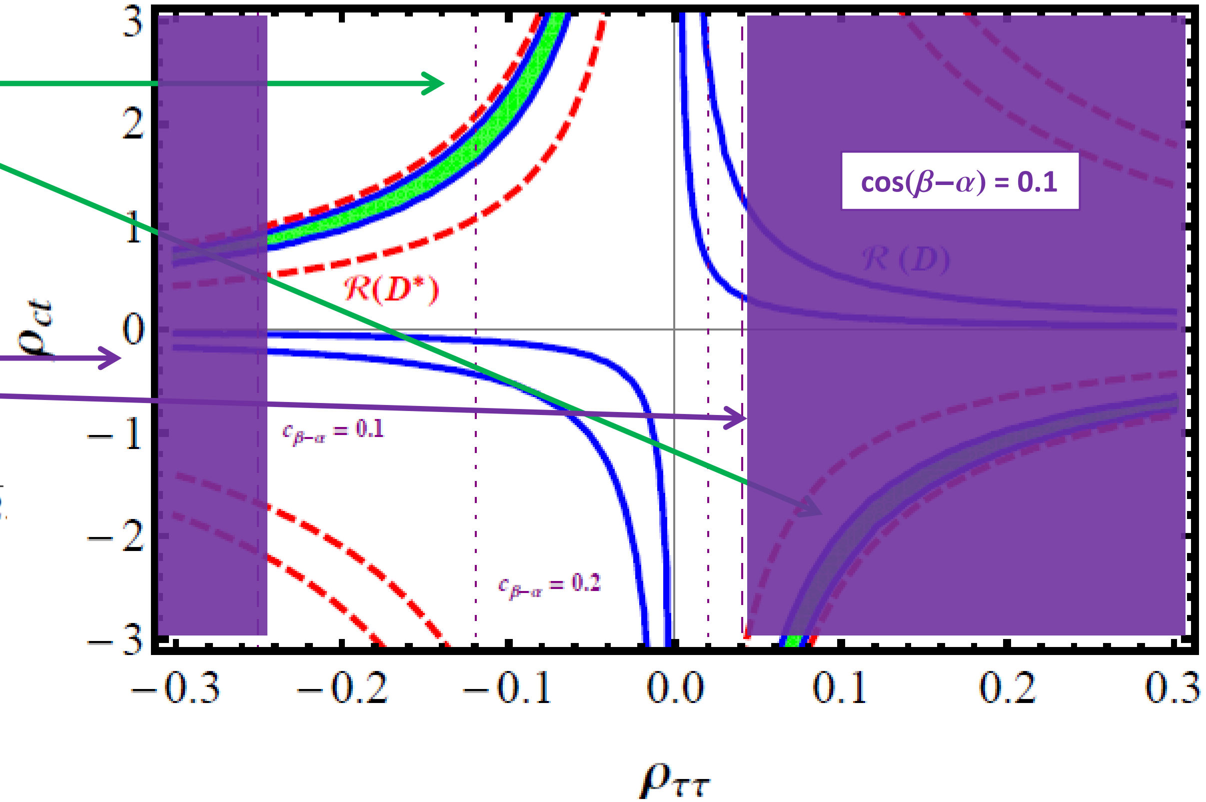
by R(D) and R(D*)

h → $\tau\tau$ (VBF) (95%CL):
[ATLAS-CONF-2012-160]

$$|s_{\beta-\alpha} + (\rho_{\tau\tau} v/\sqrt{2} m_\tau) c_{\beta-\alpha}| \lesssim \sqrt{2}$$



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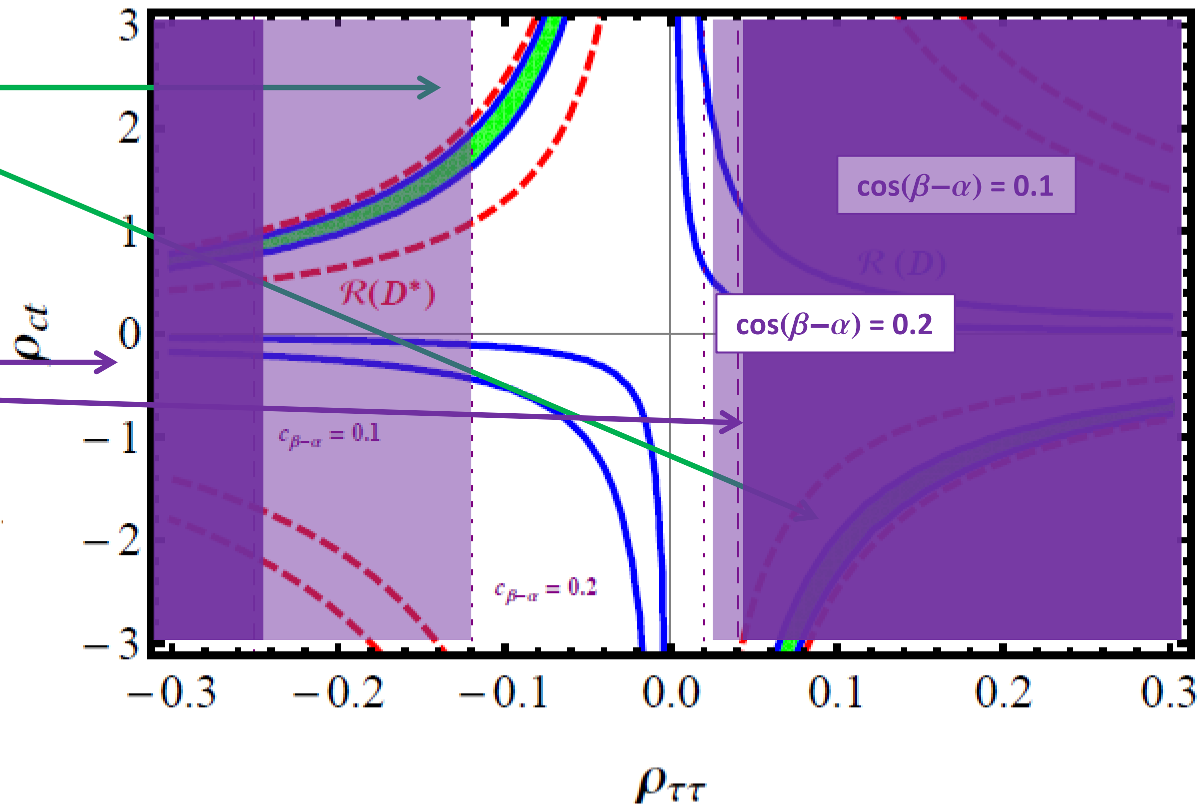

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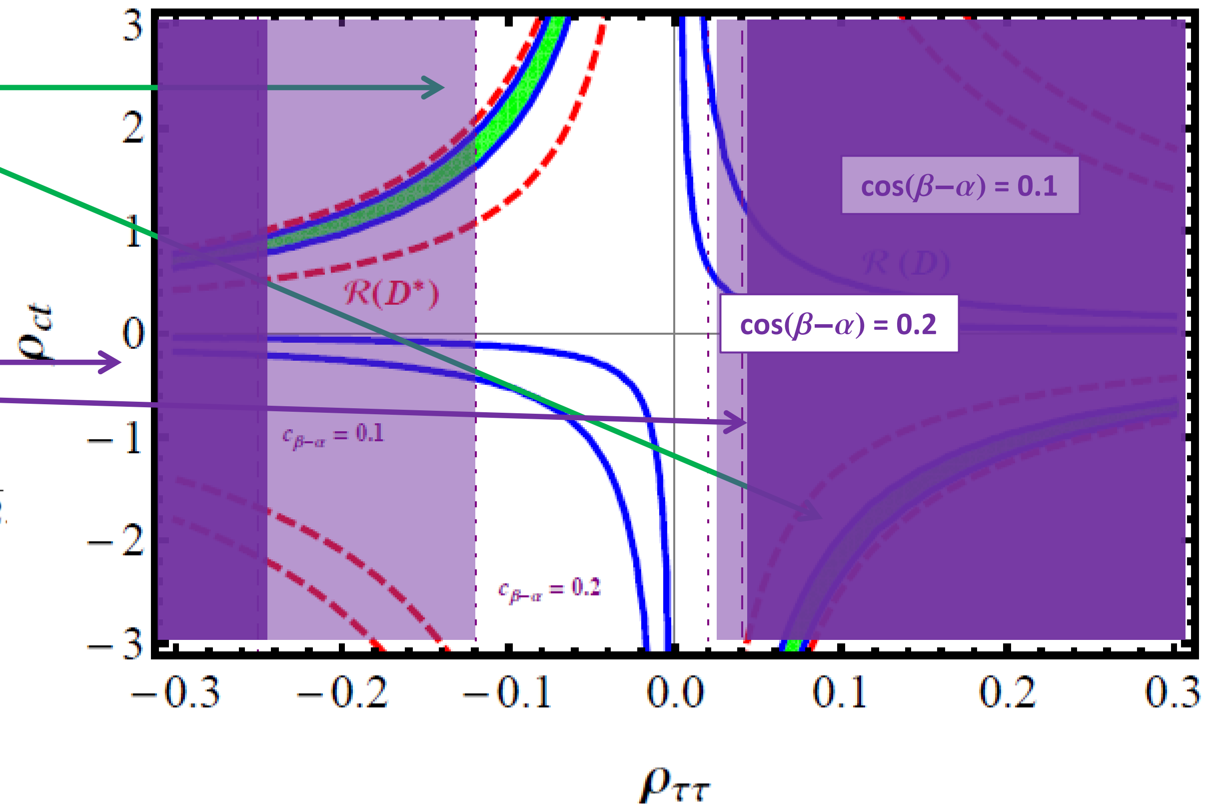
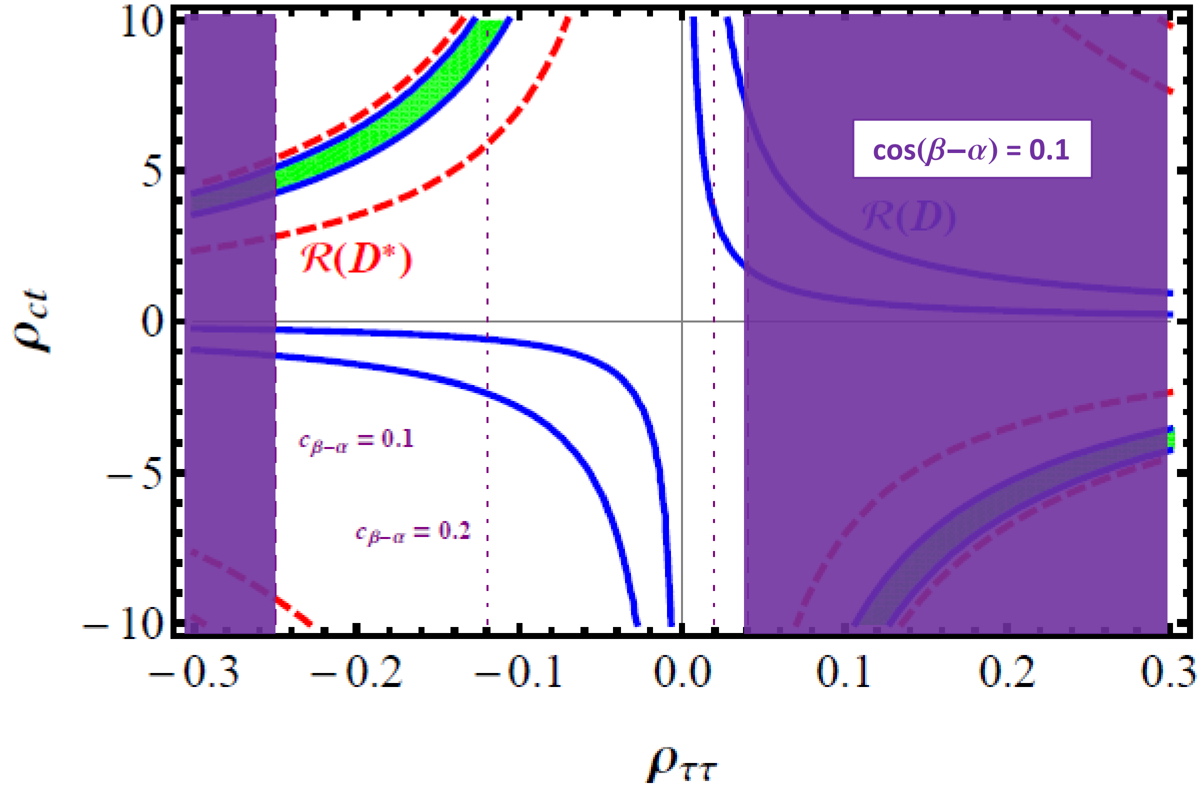


ρ_{ct} ~ 1 or larger is favored when cos($\beta-\alpha$) ≧ 0.1

Constraint by data (m_{H^+} = 700 GeV)



- nonzero cos($\beta-\alpha$) is required for nonzero t → ch $\quad \rho_{ct} \cos(\beta - \alpha)\bar{c}th + \mathrm{H.c.}$
- but, finite cos($\beta-\alpha$) tend to push ρ_{ct} nonperturbatively large
- lower charged Higgs mass is preferable in this sense

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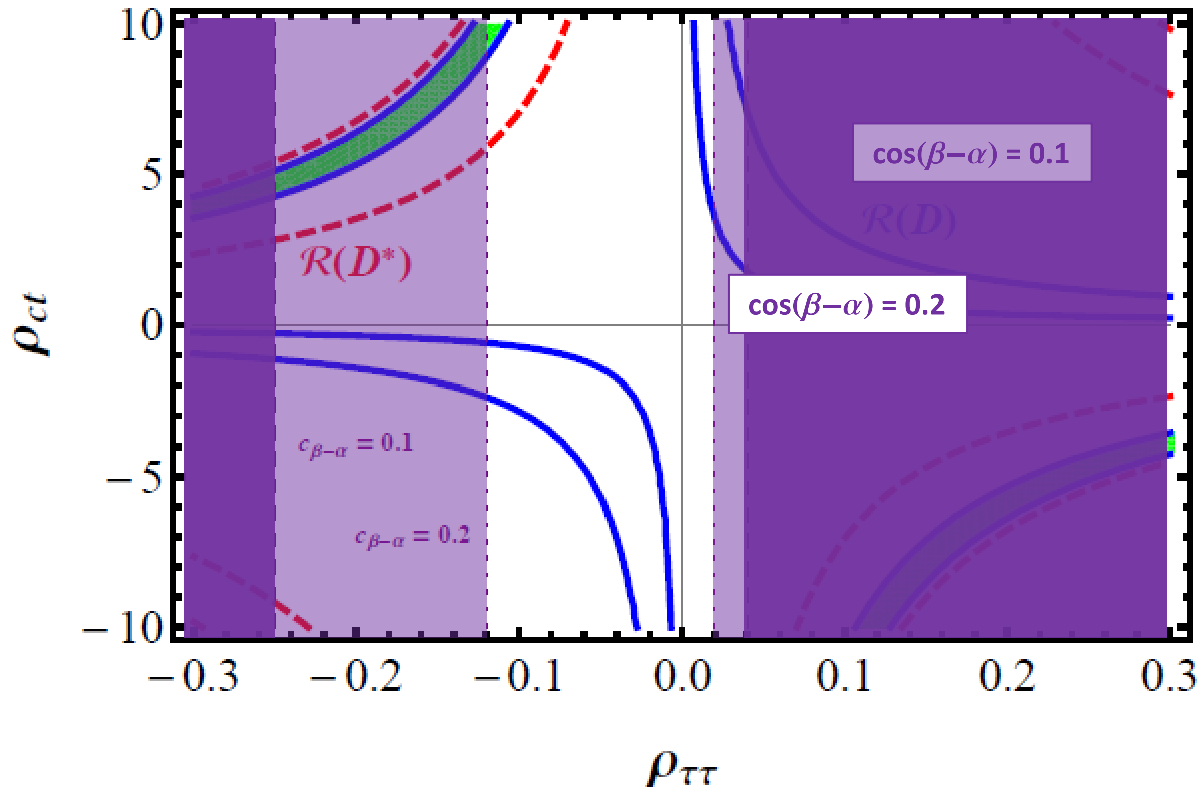

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b → sγ bound in 2HDM-III with ρ_{ct} = 1

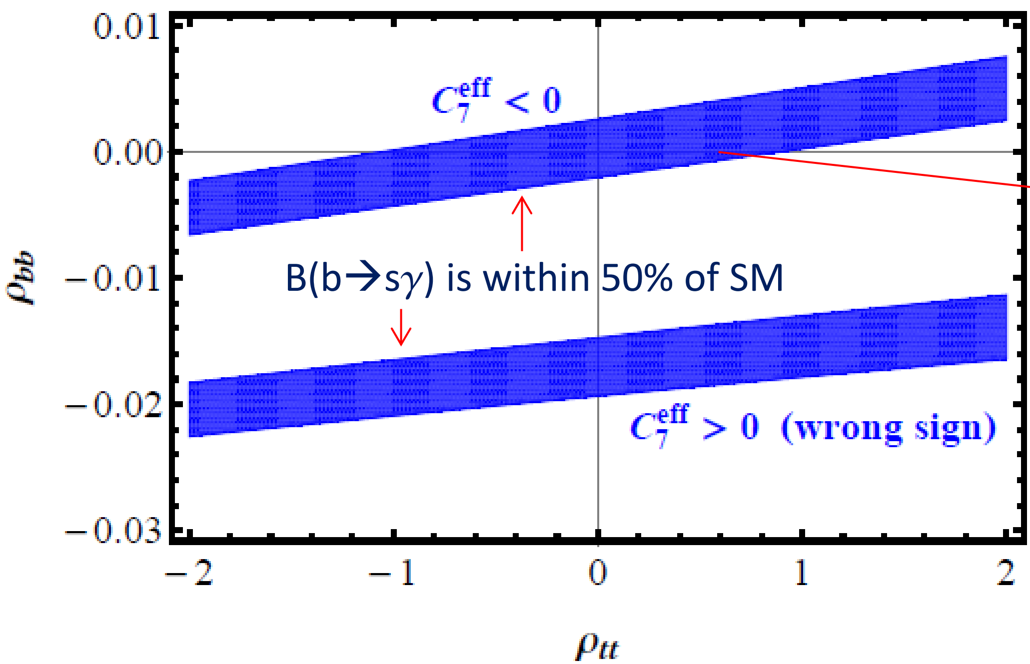
Notation follows, Ciuchini et al., NPB (1998)

$$\mathcal{H}_{\rm eff} = -\frac{4G_F}{\sqrt{2}} V_{ts}^* V_{tb} C_7 Q_7 + \ldots \qquad Q_7 = \frac{e}{16\pi^2} m_b (\bar{s}_L \sigma^{\mu\nu} b_R) F_{\mu\nu}$$

$$\delta C_{7,8}(\mu_W) \simeq \frac{1}{3}\left(\rho_{tt} + \frac{V_{cs}^*}{V_{ts}^*}\rho_{ct}\right)\left(\rho_{tt}^* + \frac{V_{cb}}{V_{tb}}\rho_{ct}^*\right)\frac{F_{7,8}^{(1)}(y)}{2m_t^2/v^2} - \left(\rho_{tt} + \frac{V_{cs}^*}{V_{ts}^*}\rho_{ct}\right)\rho_{bb}\frac{F_{7,8}^{(2)}(y)}{2m_t m_b/v^2}$$

CKM enhanced

m_{H^+} = 700 GeV



ρ_{ct} ~ 1 → tiny ρ_{bb}

$$|\rho_{bb}| \lesssim 0.01$$

cf. $\kappa_{bb} \simeq 0.02$

→ hbb coupling is SM-like

b → sγ bound in 2HDM-III with ρ_{ct} = 1

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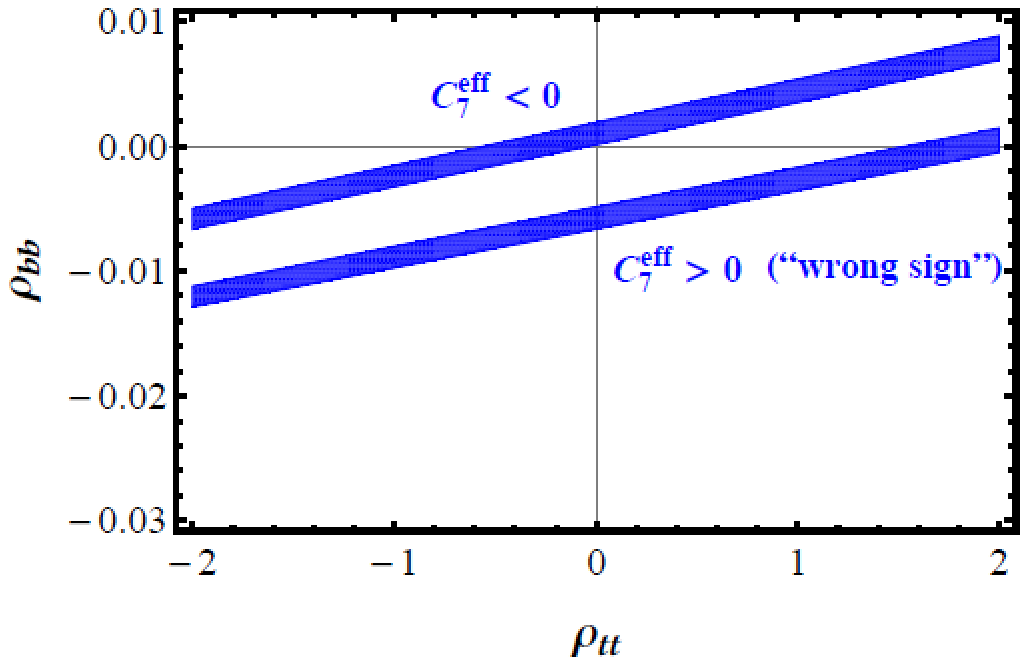
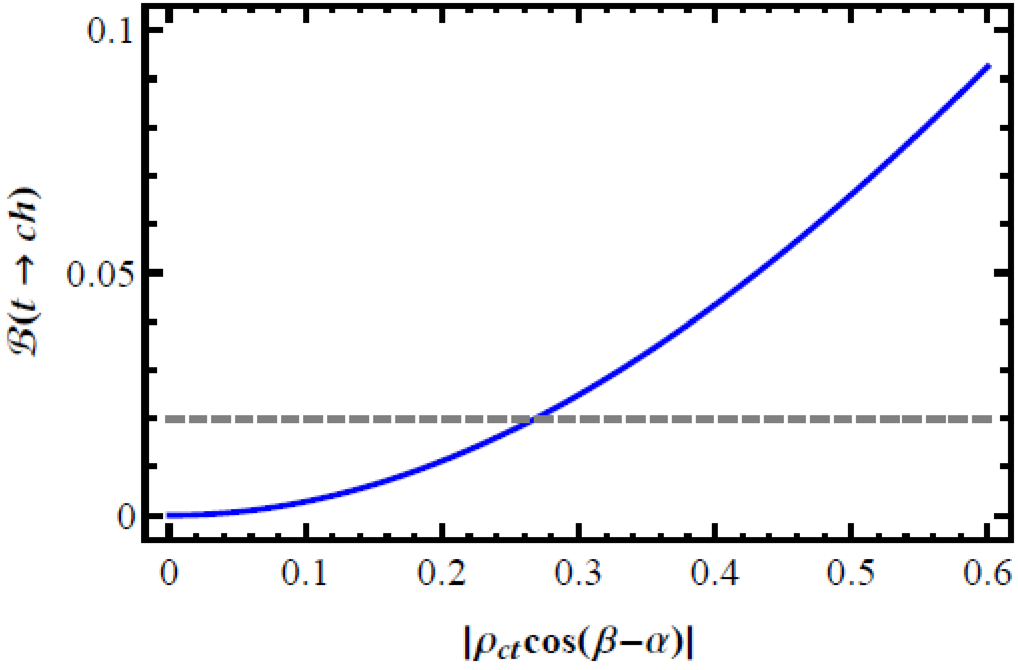
m_{H^+} = 300 GeV

CKM enhanced



300 GeV H$^+$ is allowed
in contrast to type-II case
(though fined-tuned region)

t → c h search at the LHC



Search for t → c h in top-anti-top events

- tt(bar) production cross section is large

  $\sigma_{t\bar{t}} = 220 \text{ pb}$ [LHC8] Czakon and Mitov, JHEP (2013)

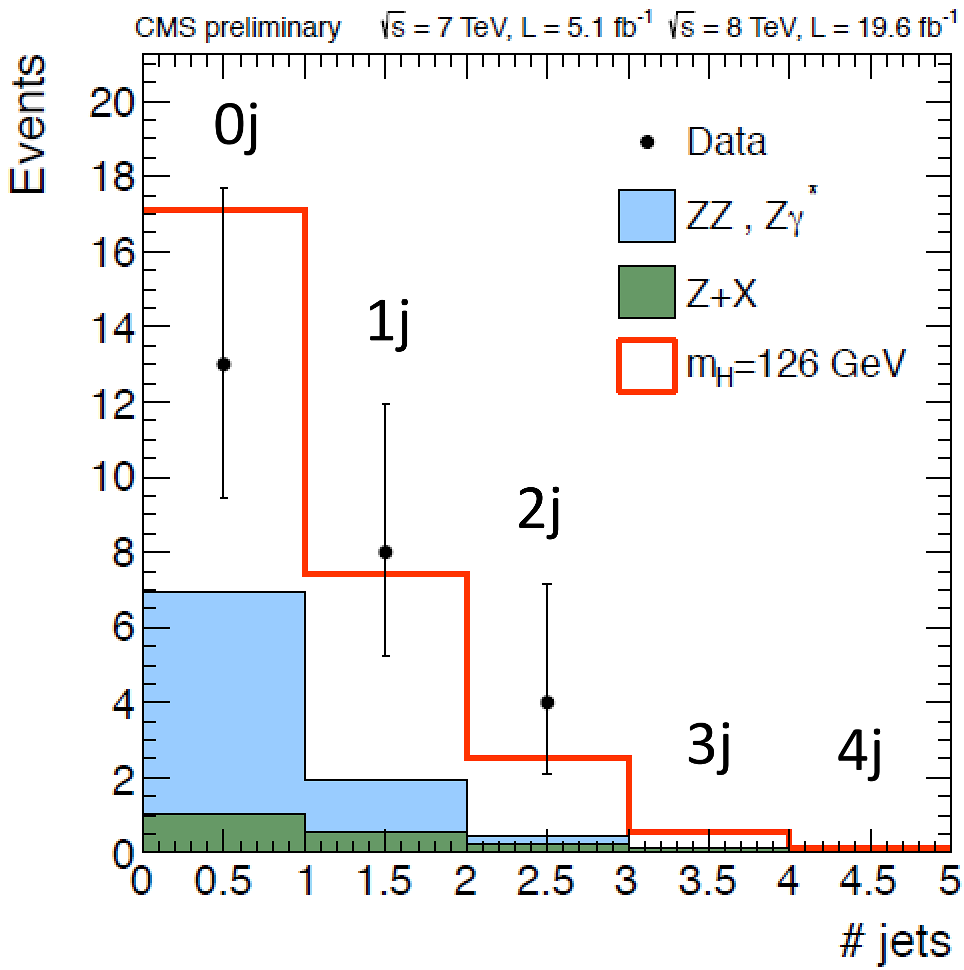
- $pp \to t\bar{t} \to bWch$ → h + 4jets / h + 2jets + l + MET

  $$\sigma(pp \to t\bar{t} \to bWch) \sim 9 \text{ pb} \times \left[\frac{\mathcal{B}(t \to ch)}{0.02}\right]$$ [LHC8]

  vs. $\sigma_{gg\to h} \sim 19 \text{ pb}$ [LHC8]

- existing LHC data (2011 + 2012) would be sensitive to B(t→ch) ~ O(1)%

Any extra jets in h → ZZ* →4l events?



- M_{4l} = [121.5 –130.5] GeV
- sum of 4e, 4μ, 2e2μ channels

- No evidence for extra jets → bound on B(t → ch)
- 95%CL limit obtained by simple use of standard CLs method:

$$\sigma(pp \to t\bar{t} \to bWch) < 6.5 \text{ pb}$$

$$\to \mathcal{B}(t \to ch) < 1.5\%$$

Actual experimental studies should do better

https://twiki.cern.ch/twiki/bin/view/CMSPublic/Hig13002TWiki

Use of other Higgs decay modes

- h → WW* & $\tau\tau$ Craig et al., PRD'12
  - study of multi-lepton final states using CMS 7TeV data:

    B(t→ch) < 2.7% … can be updated w/ latest data

- h → bb C. Kao, H.-Y. Cheng, W.-S. Hou and J. Sayre, PLB'12
  - Signal: $pp \to t\bar{t} \to bWch \to bbb + c + \ell\nu$
  - With full LHC8 data, 5σ discovery is possible for B(t→ch) > 0.3%

    [if B(h→bb) is SM-like]

- h → $\gamma\gamma$
  - recently, ATLAS reported first result for t→ch (next slides)

    ATLAS-CONF-2013-081

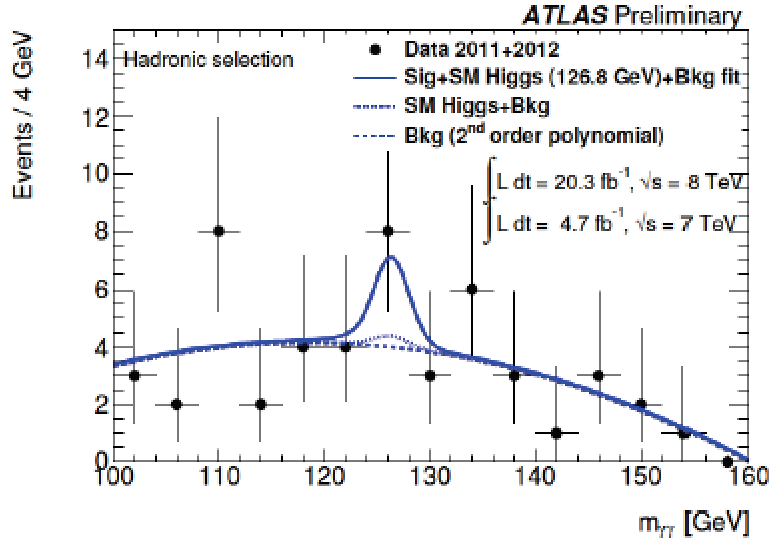
ATLAS results for t → c h(→$\gamma\gamma$)

Hadronic channel (7+8 TeV combined)

N_{obs} (full range) = 50

$N^{SM}_{H} = 0.275 \pm 0.100$ (theory+lumi)

N_{FCNC} [B(t->cH)=1%] =
$(1.58 \pm 0.12)_{(7TeV)} + (9.30^{+0.65}_{-0.72})_{(8TeV)}$



Lepton channel (8 TeV)

N_{obs} (full range) = 1

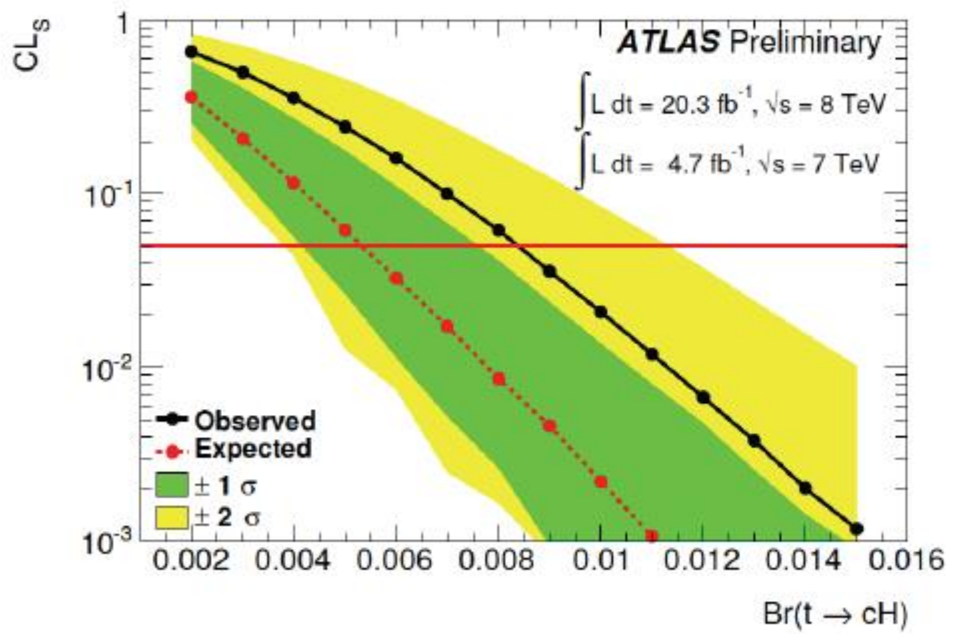
$N^{SM}_{H} = 0.053 \pm 0.008$ (theory+lumi)

N_{FCNC} [B(t->cH)=1%] = $(2.91^{+0.24}_{-0.27})$

N (had+lept) = $3.7^{+4.4}_{-3.7}$ events

ATLAS results for t → c h(→$\gamma\gamma$)

Limits



B(t → cH) < 0.83% (0.53% expected) @ 95 % CL

corresponding to a limit on the tcH coupling of :
$\lambda_{tcH} \sim 1.91\ B^{0.5} < 0.17$ (0.14 expected)

Discussions

$\rho_{ct},\ \rho_{tt},\ \rho_{cc}$

- Properties of the light Higgs h can be modified in 2HDM-III
- Need simultaneous study of t → c h and Higgs properties (not done in our study)
- Light Higgs properties when ρ_{ct} ~ 1 with small finite cos($\beta-\alpha$)

	$\mathcal{B}^{\rm SM}$	$\Gamma^{\rm SM}$[MeV]	Γ	Comment
WW^*	21.5%	0.98	hard to change	$\sin(\beta-\alpha)\simeq 1$
ZZ^*	2.7%	0.12	hard to change	$\sin(\beta-\alpha)\simeq 1$
$\gamma\gamma$	0.24%	0.011	hard to change	W-loop dom.
bb	59.4%	2.70	hard to change	$b\to s\gamma$
$\tau\tau$	5.7%	0.26	within fac. 2	direct
cc	2.6%	0.12	up to $\sim\Gamma_{b\bar{b}}$	not measured ($\rho_{cc}\lesssim 0.2$)
gg	7.7%	0.35	up to fac. 2	$\rho_{tt}\sim 1$

Crivellin et al., arXiv:1303.5877

Summary

- It is of great interest to search for the link between the top quark (t) and the Higgs boson (h)

- Large t-c-h coupling has great impact on flavor physics

- Existing LHC data have sensitivity to B(t → ch) at 1% level or below by various methods

- Actual experimental studies may do better
  ← recent ATLAS result (h→$\gamma\gamma$): B(t→ch) < 0.83% (95%CL)

- If t → ch is discovered with present data, it would suggest the existence of an extended Higgs sector beyond the usual 2HDM-II implied by MSSM, so it has a great impact!