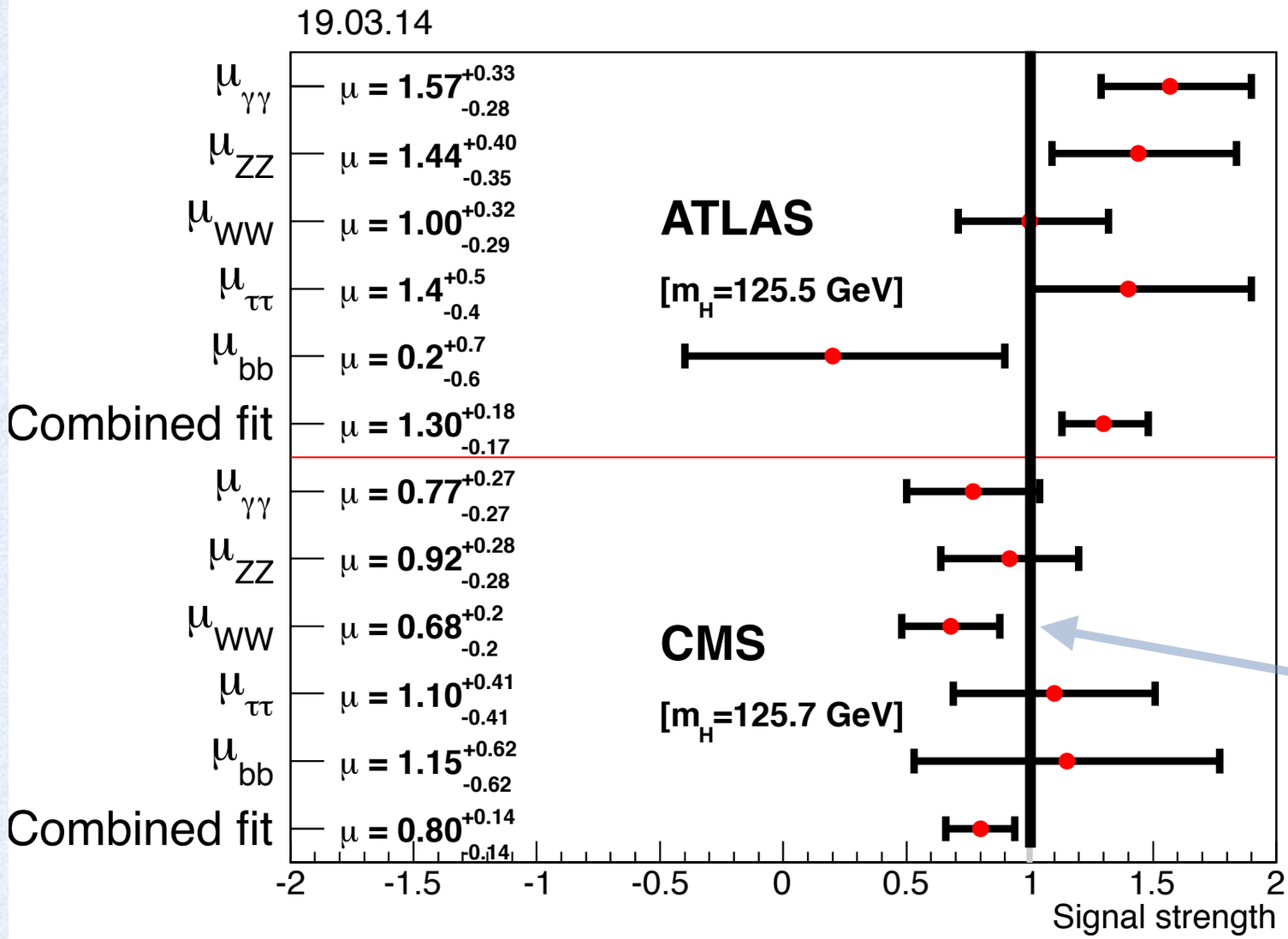
מכון ויצמן למדע
WEIZMANN INSTITUTE OF SCIENCE

THE FLAVOR STRUCTURE OF THE HIGGS

Yotam Soreq

review

INTRODUCTION

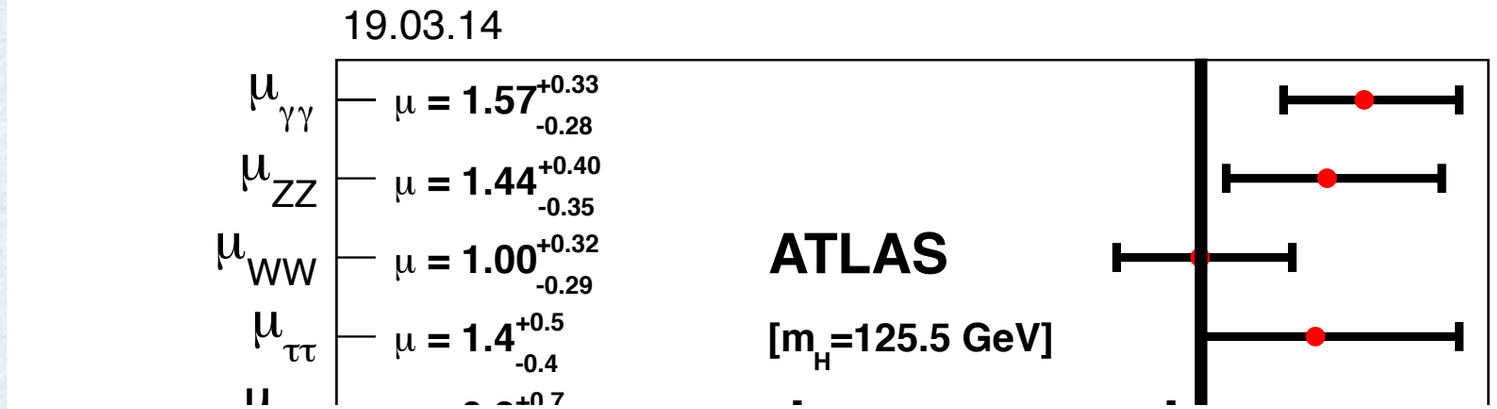


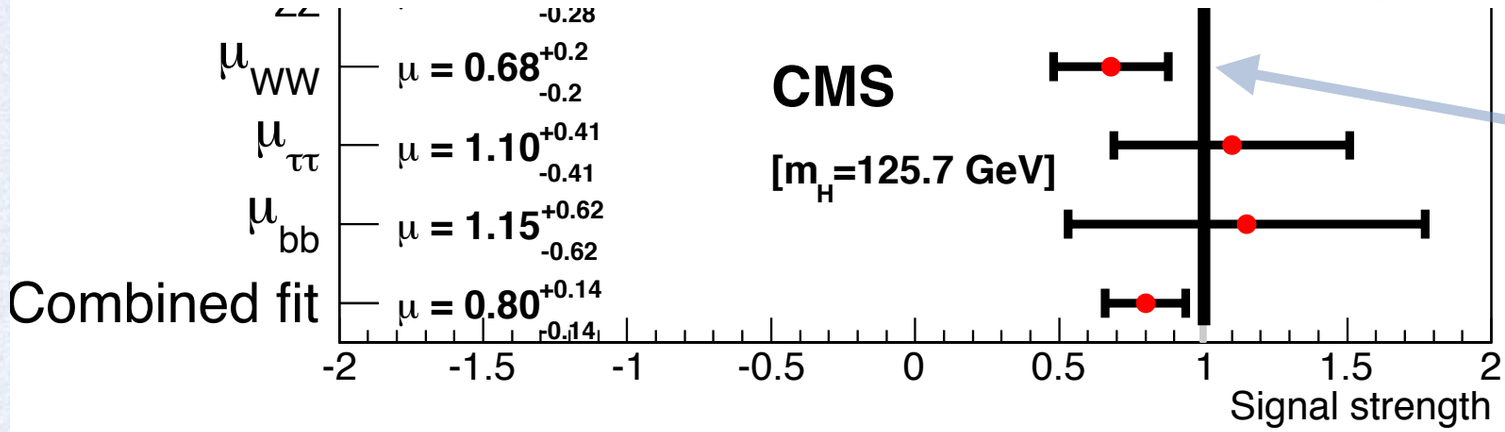
SM

$$\mu_f = \frac{\sigma_{pp\to h}\mathrm{BR}_{h\to f}}{\sigma^{\mathrm{SM}}_{pp\to h}\mathrm{BR}^{\mathrm{SM}}_{h\to f}}$$

E. Gross Moriond 2014

INTRODUCTION





what is missing?

SM

$$\mu_f = \frac{\sigma_{pp\to h}\mathrm{BR}_{h\to f}}{\sigma^{\mathrm{SM}}_{pp\to h}\mathrm{BR}^{\mathrm{SM}}_{h\to f}}$$

E. Gross Moriond 2014

INTRODUCTION

$$\mathcal{L}_Y = Y^u_{ij}\bar{u}^i_L u^j_R h + Y^d_{ij}\bar{d}^i_L d^j_R h + Y^\ell_{ij}\bar{\ell}^i_L \ell^j_R h + h.c.$$

$$y_f^{\rm SM} = \frac{m_f}{v}$$

SM

- non-universal and hierarchical
- diagonal

INTRODUCTION

What can we learn from the data on the "the flavor structure of the Higgs"?

Is there room for new physics? Where?

INTRODUCTION

- Higgs data:
  - Dedicated searches for Yukawa couplings - mainly to 3rd generation ($h\to bb$, $h\to\tau\tau$, tth, $t\to hj$).
  - Indirect constraints (total width, untagged decays).
- Low-energy processes - indirect constraints ($\mu\to e\gamma$, meson mixing and more).

INTRODUCTION

$m_h \approx 126\,\mathrm{GeV}$

$(< m_t,\, 2m_W,\, 2m_Z)$

SM

main decay mode to bottom pairs, 56%

small coupling, 0.02

modified couplings to the SM particles or to new particles

(that compete with the Higgs to bottom coupling)

a significant change to the Higgs phenomenology

the lepton sector

THE LEPTON SECTOR

diagonal:

$$\mu_{ee}^{\rm CMS} < 4.8 \times 10^4$$

$$Y^\ell = \begin{pmatrix} y_e & y_{e\mu} & y_{e\tau} \\ y_{\mu e} & y_\mu & y_{\mu\tau} \\ y_{\tau e} & y_{\tau\mu} & y_\tau \end{pmatrix}$$

$$\mu_{\mu\mu}^{\rm CMS} < 7.4$$

$$\mu_{\tau\tau} = 0.94 \pm 0.23 \quad \text{(ATLAS+CMS)}$$

$$\frac{\mu_{\mu\mu}^{\rm universal}}{\mu_{\tau\tau}^{\rm universal}} = \frac{m_\tau^2}{m_\mu^2} \approx 280$$

$$\mu_{\mu\mu}/\mu_{\tau\tau} < 15$$

universality is excluded

THE LEPTON SECTOR

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indirect constraints from current Higgs data

$$y_{\ell\ell'}/y_b^{\rm SM} \lesssim 1.2(1.9) \quad @\ 95\%\ \text{CL}$$

untagged width from Bechtle et al. 1403.1582

THE LEPTON SECTOR

off-diagonal:

$$Y^\ell = \begin{pmatrix} y_e & y_{e\mu} & y_{e\tau} \\ y_{\mu e} & y_\mu & y_{\mu\tau} \\ y_{\tau e} & y_{\tau\mu} & y_\tau \end{pmatrix}$$

$$\sqrt{|y_{\mu e}|^2 + |y_{e\mu}|^2} < 3.6 \times 10^{-6} \ (\mu \to e\gamma)$$

$$\sqrt{|y_{\tau e}|^2 + |y_{e\tau}|^2} < 1.4 \times 10^{-2} \ (\tau \to e\gamma)$$

$$\sqrt{|y_{\tau\mu}|^2 + |y_{\mu\tau}|^2} < 1.6 \times 10^{-2} \ (\tau \to \mu\gamma)$$

Harnik, Kopp, Zupan 1209.1397

Blankenburg, Ellis, Isidori 1202.5704

THE LEPTON SECTOR

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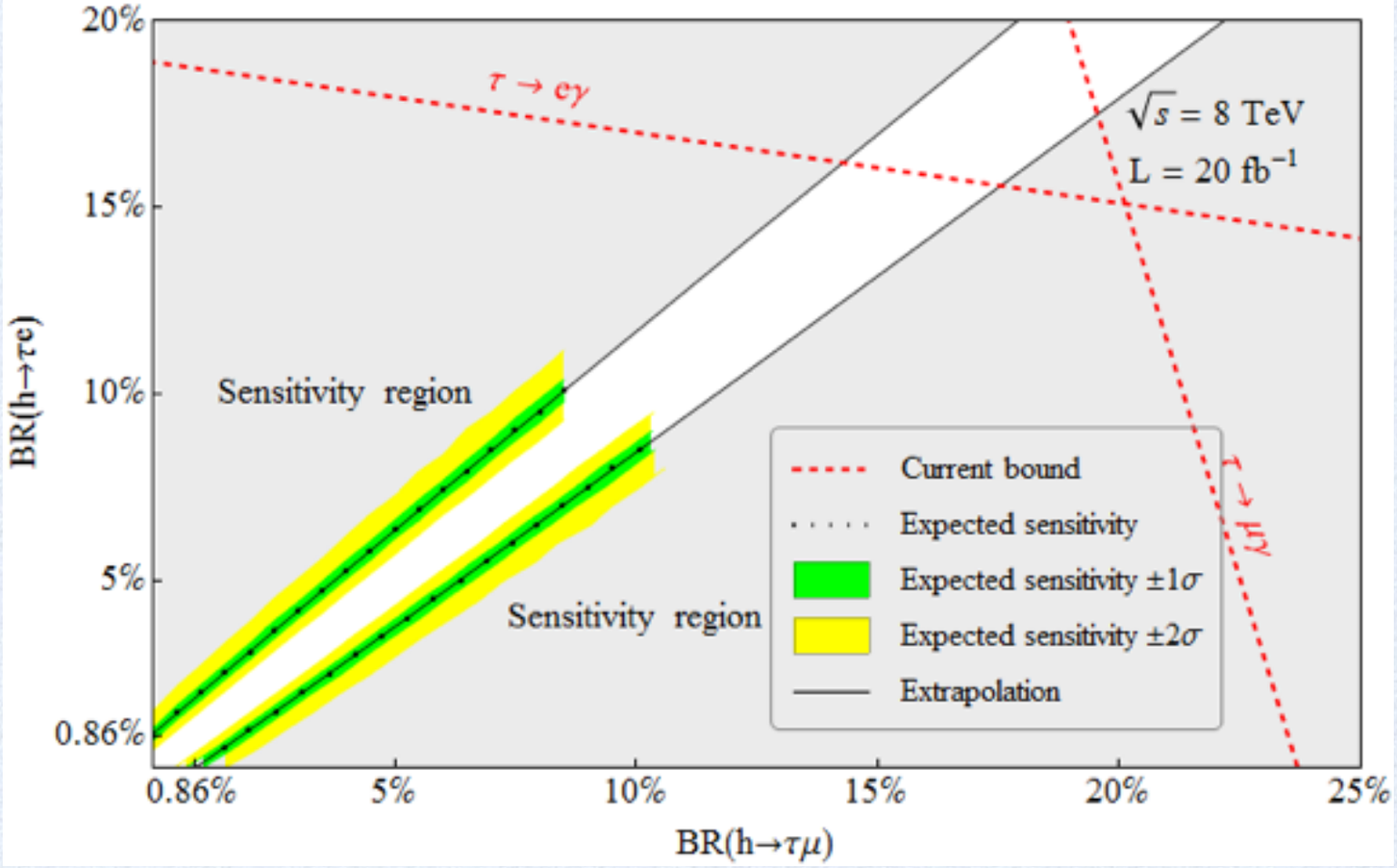
Harnik, Kopp, Zupan 1209.1397

Blankenburg, Ellis, Isidori 1202.5704

direct probe of

$\mathrm{BR}(h \to \tau\mu) - \mathrm{BR}(h \to \tau e)$

Bressler, Dery, Efrati
1405.4545



the quark sector

THE QUARK SECTOR

3rd generation:

$$Y^d = \begin{pmatrix} y_d & y_{ds} & y_{db} \\ y_{sd} & y_s & y_{sb} \\ y_{bd} & y_{bs} & y_b \end{pmatrix} \qquad Y^u = \begin{pmatrix} y_u & y_{uc} & y_{ut} \\ y_{cu} & y_c & y_{ct} \\ y_{tu} & y_{tc} & y_t \end{pmatrix}$$

$$\mu_{b\bar{b}}^{\rm CMS} = 1.0 \pm 0.5$$

$$\mu_{b\bar{b}}^{\rm ATLAS} = 0.2 \pm 0.7$$

$$t \to qh$$

$$\sqrt{|y_{tq}|^2 + |y_{qt}|^2} < 0.17$$

ATLAS

$$\mu_{t\bar{t}h}^{\rm CMS} = 2.5 \pm 1$$

$$\mu_{t\bar{t}h}^{\rm ATLAS} = 1.7 \pm 1.4$$

What about the other quark Yukawas?

THE QUARK SECTOR

off-diagonal:

$$Y^u = \begin{pmatrix} y_u & y_{uc} & y_{ut} \\ y_{cu} & y_c & y_{ct} \\ y_{tu} & y_{tc} & y_t \end{pmatrix} \qquad |y_{cu}|^2,\ |y_{uc}|^2 < 5.0 \times 10^{-9}\ (D^0 - \overline{D}^0)$$

$$Y^d = \begin{pmatrix} y_d & y_{ds} & y_{db} \\ y_{sd} & y_s & y_{sb} \\ y_{bd} & y_{bs} & y_b \end{pmatrix}$$

$$|y_{sb}|^2,\ |y_{bs}|^2 < 1.8 \times 10^{-6}\ (B_s^0 - \overline{B}_s^0)$$

$$|y_{db}|^2,\ |y_{bd}|^2 < 2.3 \times 10^{-8}\ (B_d^0 - \overline{B}_d^0)$$

$$Im(y_{ds}^2,\ y_{sd}^2) < 2.9 \times 10^{-12}\ (K^0 - \overline{K}^0)$$

$$Re(y_{ds}^2,\ y_{sd}^2) < 5.6 \times 10^{-10}\ (K^0 - \overline{K}^0)$$

Blankenburg, Ellis, Isidori
1202.5704

Harnik, Kopp, Zupan
1209.1397

THE QUARK SECTOR

what about the other quark Yukawas? from the Higgs data

naive χ^2:

$$y_{qq'}/y_b^{\rm SM} \lesssim 0.7(1.4) \quad @\,95\%\ {\rm CL}$$

Delaunay, Golling, Perez, YS 1310.7029

Kagan, Perez, Petriello, YS, Stoynev, Zupan work in progress

a significant enhancement of the light-quark Yukawas is allowed

THE QUARK SECTOR

example, enhanced charm Yukawa:

- $h \to bb$ is suppressed $\mu_{b\bar{b}} \equiv \dfrac{\sigma_{pp\to h}\mathrm{BR}_{h\to b\bar{b}}}{\sigma^{\mathrm{SM}}_{pp\to h}\mathrm{BR}^{\mathrm{SM}}_{h\to b\bar{b}}} \sim 0.8(0.6)$ Delaunay, Golling, Perez, YS 1310.7029

- probed by charm tagging $\Rightarrow \mu_{b\bar{b}+c\bar{c}}/\mu_{b\bar{b}} > 1$ c-tagging, ATLAS -CONF-2013-068

- probed by Higgs to quarkonia $h \to J/\psi\gamma$ Bodwin, Petriello, Stoynev, Velasco 1306.5770

other Yukawas (light and off-diagonal) by exclusive decays

$h \to \phi\gamma\,,\ \rho\gamma\,,\ \omega\gamma\,,\ \bar{B}^{0*}_s\gamma\,,\ \bar{B}^{0*}\gamma\,,\ D^{0*}\gamma$ Kagan, Perez, Petriello, YS, Stoynev, Zupan work in progress

SUMMARY

- The "flavor Higgs era" has begun.
- The current measurements mainly probe the Higgs couplings to third generation fermions.
- There is room for new physics mainly in the off-diagonal Higgs couplings and in the couplings to the first two generations.

BACKUP SLIDES

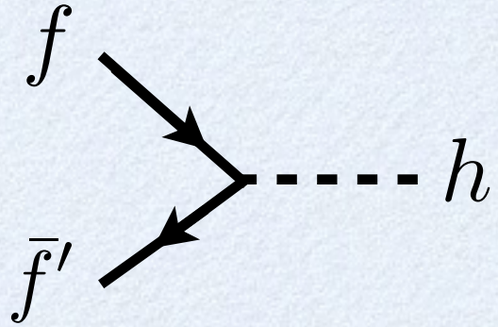
INTRODUCTION

example of $y_{ff'} > y_{ff'}^{\rm SM}$:

$m_f + m_{f'} < m_h$ $\quad \Gamma_h \Uparrow$ $\quad \mathrm{BR}(h \to f\bar{f}') \Uparrow$

$\mathrm{BR}(h \to g) \Downarrow \quad g \neq f\bar{f}$

(measured rates are smaller)



$f,\ \bar{f}' = \mathrm{quarks}$

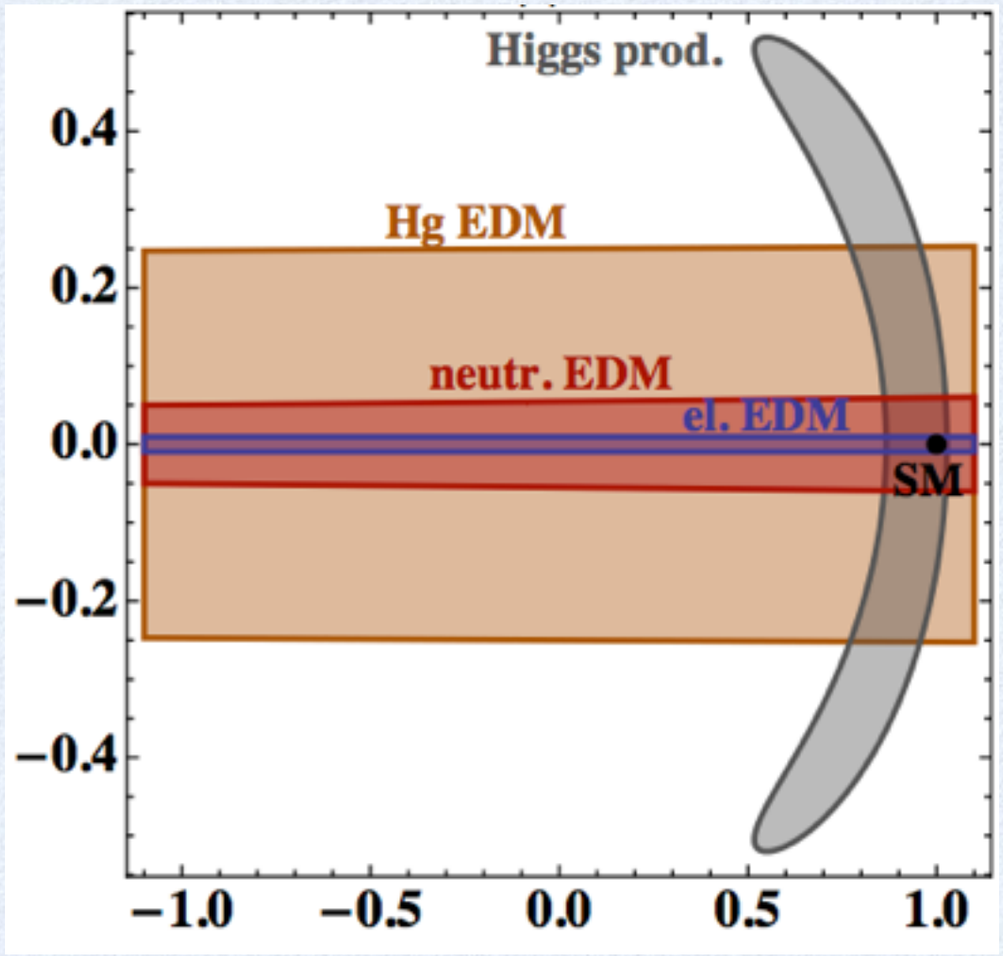
(non SM Higgs production)

indirect constraints from the current Higgs data

similar to the "untagged" branching ratio bound

CP VIOLATION

imaginary Yukawa



CP violation in the Higgs sector

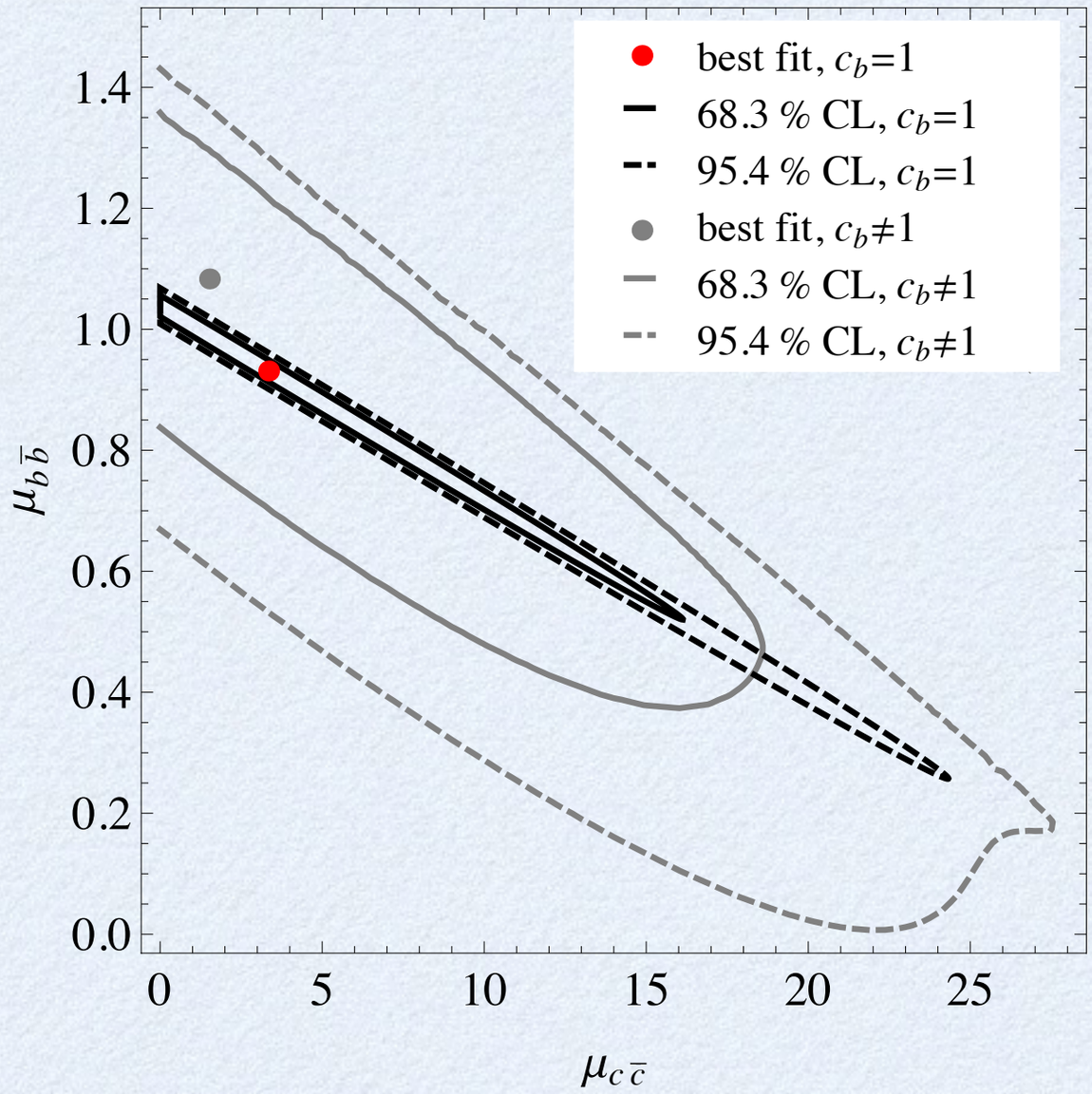
for other (not top) fermion Yukawa phase of order 1 is allowed

Brod, Haisch, Zupan
1310.1385

RELATED OBSERVABLES

- correlation between $\mu_{b\bar{b}}$ and $\mu_{c\bar{c}}$

Vh channel



$$\mu_{b\bar{b}}^{\rm SM} = \mu_{c\bar{c}}^{\rm SM} = 1$$

Delaunay, Golling, Perez, YS 1310.7029

RELATED OBSERVABLES

$$R \equiv \frac{\mu_{b\bar{b}+c\bar{c}}}{\mu_{b\bar{b}}} = \frac{1+|y_c/y_c^{\rm SM}|^2 r_{cb}^2\,{\rm SM}_{h\to c\bar{c}}^{\rm SM}/{\rm SM}_{h\to b\bar{b}}^{\rm SM}}{1+r_{cb}^2\,{\rm BR}_{h\to c\bar{c}}^{\rm SM}/{\rm SM}_{h\to b\bar{b}}^{\rm SM}}$$

$$r_{cb} \equiv \frac{\varepsilon_c}{\varepsilon_b} \simeq \frac{0.4}{0.7}$$

- BSM models for enhanced charm Yukawa

(a) EFT $\quad \mathcal{L}_{\rm EFT} \supset \lambda^u_{ij} \bar{Q}_i \tilde{H} U_j + \frac{g^u_{ij}}{\Lambda^2} \bar{Q}_i \tilde{H} U_j \left(H^\dagger H\right) + \text{h.c.}$

(b) 2HDM with MFV

(c) GMFV

(d) composite models

Delaunay, Golling,
Perez, YS 1310.7029