Constraints on Higgs FCNC Couplings from Precision Measurement of $B_s \to \mu^+\mu^-$ Decay

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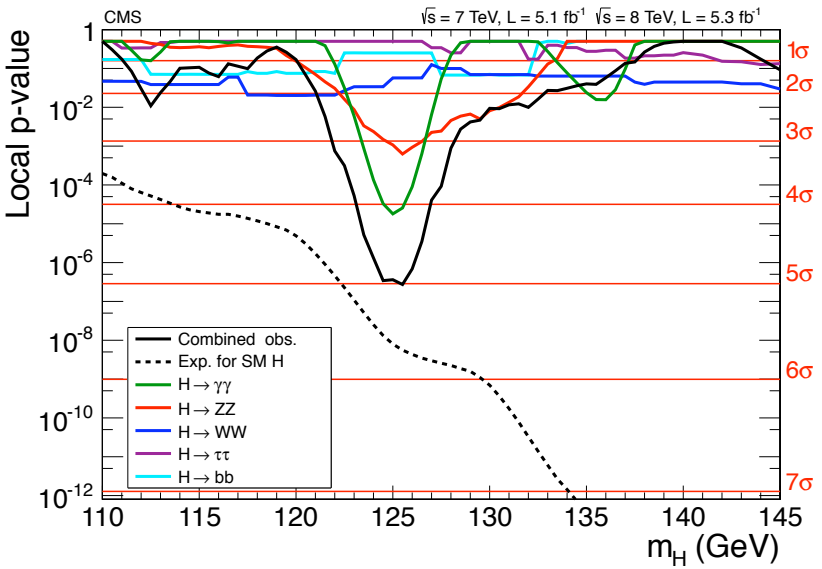
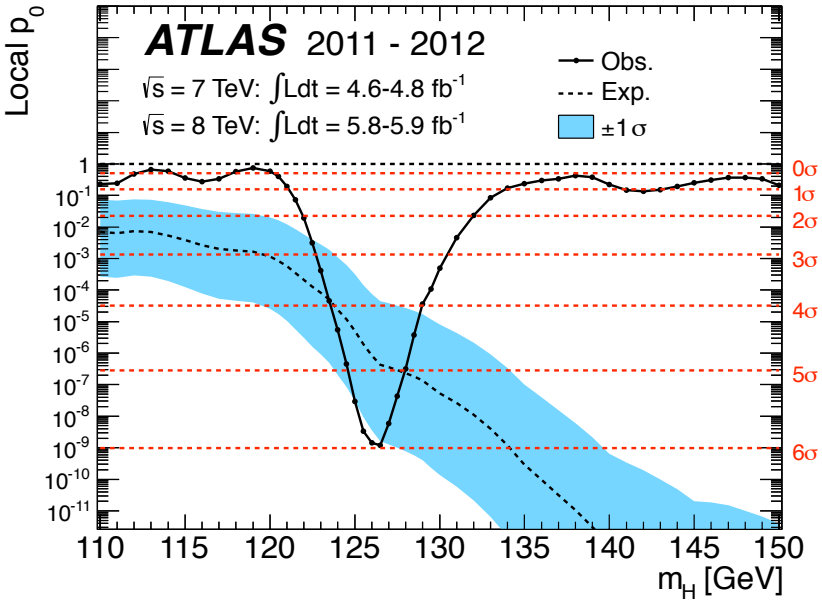
arXiv: 1703.06289, Cheng-Wei Chiang, Xiao-Gang He, Fang Ye, XY

Higgs Discovery





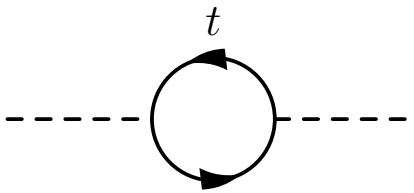
LHC Run I

- mass: $m_h = 125\,\mathrm{GeV}$ ☺
- spin ☺
- parity ☺
- Yukawa coupling ☺
- gauge coupling ☺
- self coupling ?

LHC Run II/HL

Higgs After the Discovery

Hierarchy Problem

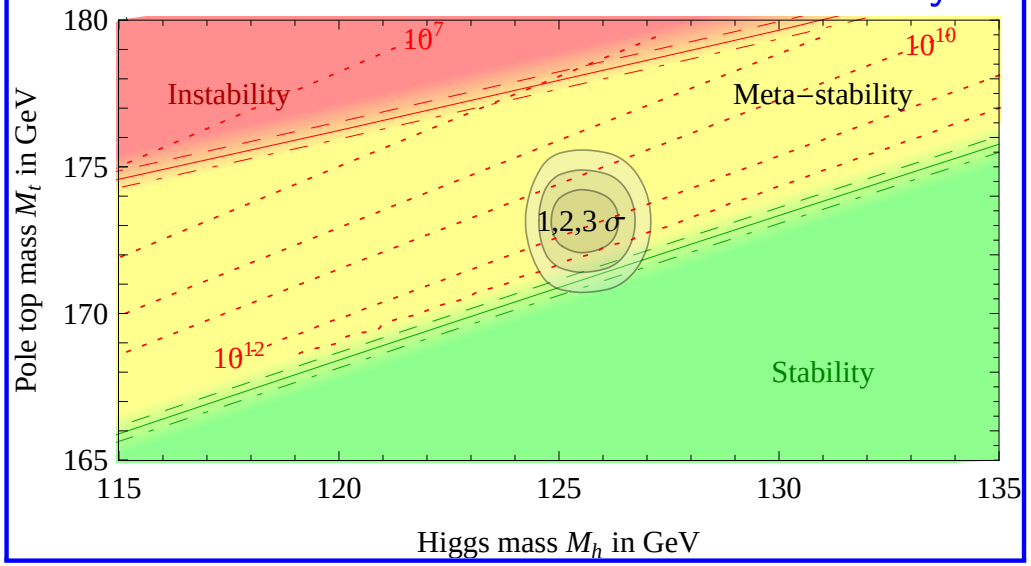


$$+ \ldots = \frac{c}{16\pi^2}\Lambda^2$$

fine-tuning

$$m_{h,0}^2 + \frac{c}{16\pi^2}\Lambda^2 = 125\,\mathrm{GeV}^2$$

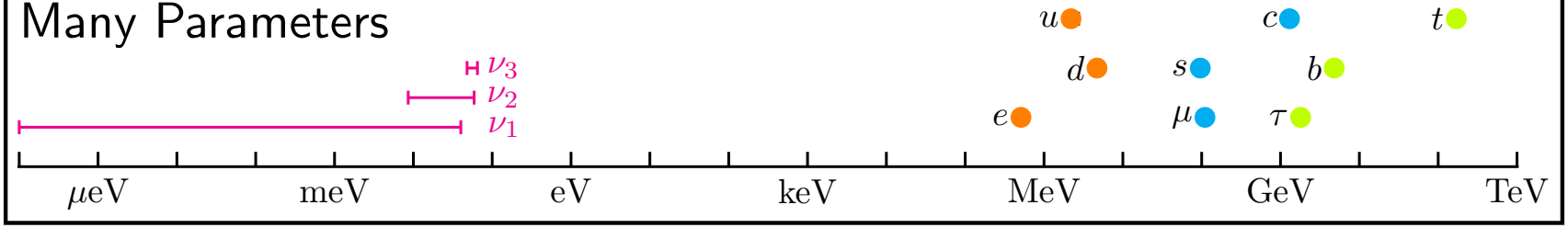
Vacuum Stability



$$\Delta\mathcal{L}_H = +\mu^2\Phi^\dagger\Phi - \lambda\left(\Phi^\dagger\Phi\right)^2 + (2m_W^2 W_\mu^+ W^{-\mu} + m_Z^2 Z_\mu Z^\mu)\frac{h}{v} - m_i\bar{f}_i f_i\frac{h}{v}$$

$$+h\cdot X_{\mathrm{NP}} - \frac{1}{\sqrt{2}}\bar{f}_i(\lambda_{ij} + i\gamma_5\bar{\lambda}_{ij})f_j h + \ldots$$

Many Parameters



Higgs FCNC: exp

	e	μ	τ
e	e^+e^-collider	$\mathcal{B} < 0.035\%$	$\mathcal{B} < 0.61\%$
μ		$\mu < 2.8$	$\mathcal{B} < 0.25\%$
τ			$\mu = 1.1 \pm 0.2$

	u	c	t
u			$\mathcal{B} < 0.55\%$
c			$\mathcal{B} < 0.40\%$
t			$\mu_{tth} = 2.3^{+0.7}_{-0.6}$

	d	s	b
d			
s			
b			$\mu = 0.70^{+0.29}_{-0.27}$

◀ direct search

▼ indirect study

McWilliams, Li 1981
Shanker 1982
Barr, Zee 1990
Kanemura, Ota, Tsumura 2006
Davidson, Grenier 2010
Golowich et al 2011
Buras, Girrbach 2012
Blankenburg, Ellis, Isidori 2012
Harnik, Kopp, Zupan 2013
Gorbahn, Haisch 2014
Celis, Cirigliano, Passemar 2014
... ...

Higgs FCNC in EFT

- Effective Field Theory

$$\mathcal{L}_{\text{full}} = \mathcal{L}_{\text{SM}} + \sum_i \frac{c_i}{\Lambda^2} \mathcal{O}_i^{d=6} + \dots$$

- Dim-4 operator in the SM

$$(\bar{Q}_L H Y_d d_R), \quad (\bar{Q}_L \tilde{H} Y_u u_R), \quad (\bar{Q}_L H Y_e e_R),$$

- Dim-6 operator in the EFT Grzadkowski et al., 2010, Harnik, Kopp, Zupan, 2013

$$\mathcal{O}_{uH} = (H^\dagger H)(\bar{Q}_L H C_{dH} d_R),$$
$$\mathcal{O}_{dH} = (H^\dagger H)(\bar{Q}_L \tilde{H} C_{uH} u_R),$$
$$\mathcal{O}_{eH} = (H^\dagger H)(\bar{Q}_L H C_{eH} e_R),$$

- Yukawa interaction

$$\Delta\mathcal{L} = -\left(1 + \frac{h}{v}\right) \bar{f}_L Y_f \frac{v}{\sqrt{2}} f_R - \frac{v^2}{2\Lambda^2}\left(1 + \frac{3h}{v}\right) \bar{f}_L C_{fH} \frac{v}{\sqrt{2}} f_R + h.c.$$

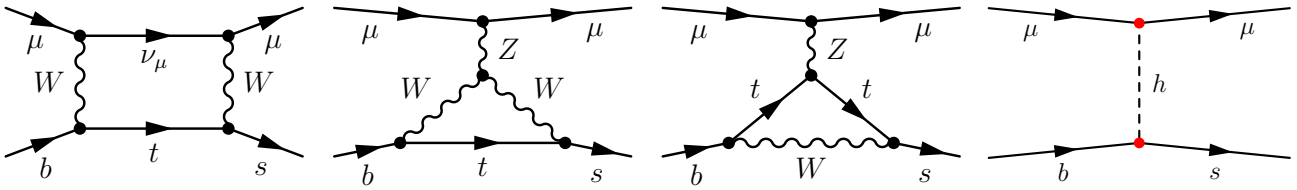
- Yukawa interaction in mass eigenstate $Y_{ij} = Y_{ji}^*$, $\bar{Y}_{ij} = \bar{Y}_{ji}^*$

$$\Delta\mathcal{L} = -\frac{1}{\sqrt{2}} \bar{f}_i (Y_{ij} + i\bar{Y}_{ij}\gamma_5) f_j h,$$

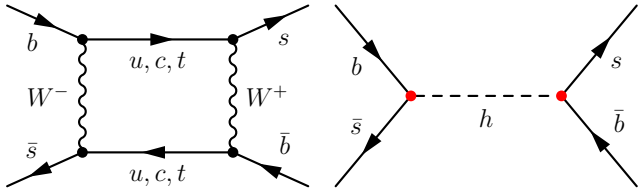
Constraints and Predictions

Constraints:

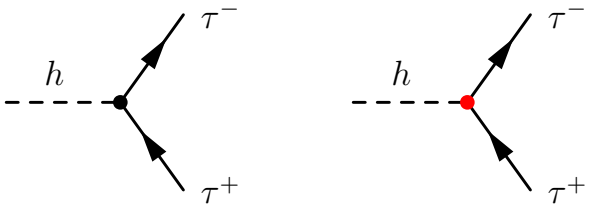
- $B_s \to \mu^+\mu^-$



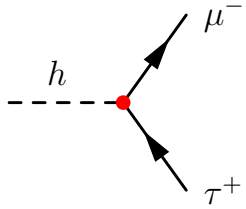
- $B_s - \bar{B}_s$



- $h \to \tau\tau$



- $h \to \mu\tau$



Predictions: $\mathcal{B}(B_s \to \mu\tau)$, $\mathcal{B}(B_s \to \tau\tau)$, ...

$B_s \to \mu^+\mu^-$ decay: SM and exp

- $\overline{\mathcal{B}}(B_s \to \mu^+\mu^-)_{\rm SM} = (3.44 \pm 0.19) \times 10^{-9}$
- $\overline{\mathcal{B}}(B_s \to \mu^+\mu^-)_{\rm avg} = (3.0 \ \pm 0.5 \ ) \times 10^{-9}$

$\overline{\mathcal{B}}(B_s \to \mu^+\mu^-)_{\rm LHCb17} = (3.0 \pm 0.6^{+0.3}_{-0.2}) \times 10^{-9}$

$\overline{\mathcal{B}}(B_s \to \mu^+\mu^-)_{\rm CMS13} = (3.0^{+1.0}_{-0.9}) \times 10^{-9}$

theoretical progress:
De Bruyn et al 2012
Bobeth et al 2013

recent study:
Altmannshofer et al 2017
Fleischer et al 2017

f_{B_s} \ $\overline{\mathcal{B}}(B_s \to \mu^+\mu^-) \times 10^{+9}$	incl.	avg.	excl.
$N_f = 2+1+1$	3.54	3.31	3.00
$N_f = 2+1$	3.68	3.44	3.11

V_{cb}, V_{ub}

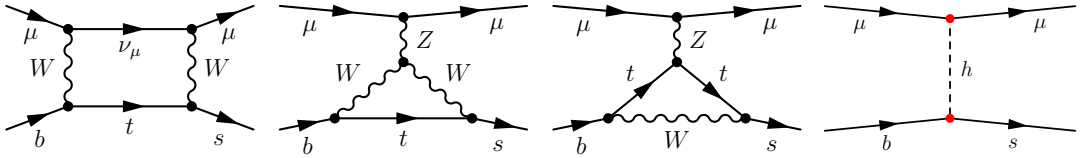
input:
$(|V_{us}|, |V_{ub}|, |V_{cb}|, \gamma)$

$$\overline{\mathcal{B}} \propto |V_{tb}^* V_{ts}|^2 f_{B_s}^2$$

	FLAG [2016] $N_f = 2+1$	HPQCD [2013] $N_f = 2+1+1$	unit
f_{B_s}	$228.4\,(3.7)$	$224\,(5)$	MeV
f_{B_d}	$192.0\,(4.3)$	$186\,(4)$	MeV

	$\lvert V_{ub}\rvert$	$\lvert V_{cb}\rvert$	$\lvert V_{tb}^* V_{ts}\rvert$	$\lvert V_{tb}^* V_{td}\rvert$	unit
sl. incl.	$4.45 \pm 0.18 \pm 0.31$	$42.42 \pm 0.44 \pm 0.74$	41.6 ± 0.8	9.1 ± 0.5	10^{-3}
sl. avg.	$3.98 \pm 0.08 \pm 0.22$	$41.00 \pm 0.33 \pm 0.74$	40.2 ± 0.8	8.8 ± 0.4	10^{-3}
sl. excl.	$3.72 \pm 0.09 \pm 0.22$	$38.99 \pm 0.49 \pm 1.17$	38.2 ± 1.2	8.3 ± 0.4	10^{-3}

$B_s \to \mu^+\mu^-$ decay: theory



- Effective Hamiltonian

$$\mathcal{H}_{\rm eff} = -\frac{G_F}{\sqrt{2}}\frac{\alpha_e}{\pi s_W^2} V_{tb}V_{ts}^*\big(C_A\mathcal{O}_A + C_S\mathcal{O}_S + C_P\mathcal{O}_P\big) + h.c.$$

- Effective operator

$$\mathcal{O}_A = (\bar{q}\gamma_\mu P_L b)(\bar{\mu}\gamma^\mu\gamma_5\mu), \quad \mathcal{O}_S = \frac{m_b m_\ell}{m_W^2}(\bar{q}P_R b)(\bar{\mu}\mu), \quad \mathcal{O}_P = \frac{m_b m_\ell}{m_W^2}(\bar{q}P_R b)(\bar{\mu}\gamma_5\mu),$$
$$\mathcal{O}_S' = \frac{m_b m_\ell}{m_W^2}(\bar{q}P_L b)(\bar{\mu}\mu), \quad \mathcal{O}_P' = \frac{m_b m_\ell}{m_W^2}(\bar{q}P_L b)(\bar{\mu}\gamma_5\mu).$$

- Branching ratio

loop suppression; helicity suppression

$$\mathcal{B}(B_q \to \ell^+\ell^-) = \frac{\tau_{B_q} G_F^4 m_W^4}{8\pi^5}|V_{tb}V_{tq}^*|^2 f_{B_q}^2 M_{B_q} m_\ell^2 \sqrt{1-\frac{4m_\ell^2}{m_{B_q}^2}}\big(|P|^2+|S|^2\big),$$

$$P \equiv C_A + \frac{m_{B_q}^2}{2m_W^2}\left(\frac{m_b}{m_b+m_q}\right)(C_P - C_P'),$$

$$S \equiv \sqrt{1-\frac{4m_\ell^2}{m_{B_q}^2}}\,\frac{m_{B_q}^2}{2m_W^2}\left(\frac{m_b}{m_b+m_q}\right)(C_S - C_S').$$

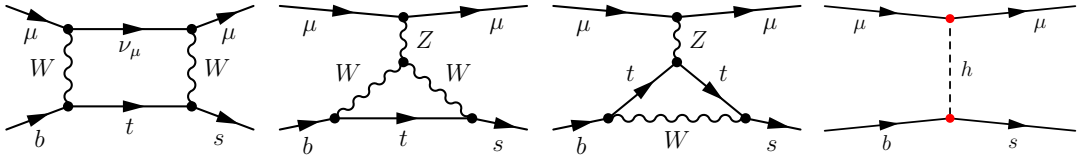
- Corrections from $B_s - \bar{B}_s$ mixing

De Bruyn et al., 2012; Fleischer 2012

$$\overline{\mathcal{B}}(B_s \to \ell^+\ell^-) = \left(\frac{1+\mathcal{A}_{\Delta\Gamma}y_s}{1-y_s^2}\right)\mathcal{B}(B_s \to \ell^+\ell^-), \qquad \mathcal{A}_{\Delta\Gamma} = \frac{|P|^2\cos 2\varphi_P - |S|^2\cos 2\varphi_S}{|P|^2+|S|^2}$$

$B_s \to \mu^+\mu^-$ can provide excellent probe for the Higgs FCNC.

$B_s \to \mu^+\mu^-$ decay: Higgs FCNC effects



- Effective Hamiltonian

$$\mathcal{H}_{\rm eff} = -\frac{G_F}{\sqrt{2}}\frac{\alpha_e}{\pi s_W^2} V_{tb}V_{ts}^*\big(C_A\mathcal{O}_A + C_S\mathcal{O}_S + C_P\mathcal{O}_P\big) + h.c.$$

- Effective operator

$$\boldsymbol{\mathcal{O}_A = (\bar q\gamma_\mu P_L b)(\bar\mu\gamma^\mu\gamma_5\mu)}, \quad \mathcal{O}_S = \frac{m_b m_\ell}{m_W^2}(\bar q P_R b)(\bar\mu\mu), \quad \mathcal{O}_P = \frac{m_b m_\ell}{m_W^2}(\bar q P_R b)(\bar\mu\gamma_5\mu),$$

$$\mathcal{O}'_S = \frac{m_b m_\ell}{m_W^2}(\bar q P_L b)(\bar\mu\mu), \quad \mathcal{O}'_P = \frac{m_b m_\ell}{m_W^2}(\bar q P_L b)(\bar\mu\gamma_5\mu).$$

- Branching ratio

loop suppression; helicity suppression

$$\mathcal{B}(B_q \to \ell^+\ell^-) = \frac{\tau_{B_q} G_F^4 m_W^4}{8\pi^5}|V_{tb}V_{tq}^*|^2 f_{B_q}^2 M_{B_q} m_\ell^2 \sqrt{1-\frac{4m_\ell^2}{m_{B_q}^2}}\big(|P|^2+|S|^2\big),$$

$$P \equiv C_A + \frac{m_{B_q}^2}{2m_W^2}\left(\frac{m_b}{m_b+m_q}\right)(C_P - C'_P),$$

$$S \equiv \sqrt{1-\frac{4m_\ell^2}{m_{B_q}^2}}\,\frac{m_{B_q}^2}{2m_W^2}\left(\frac{m_b}{m_b+m_q}\right)(C_S - C'_S).$$

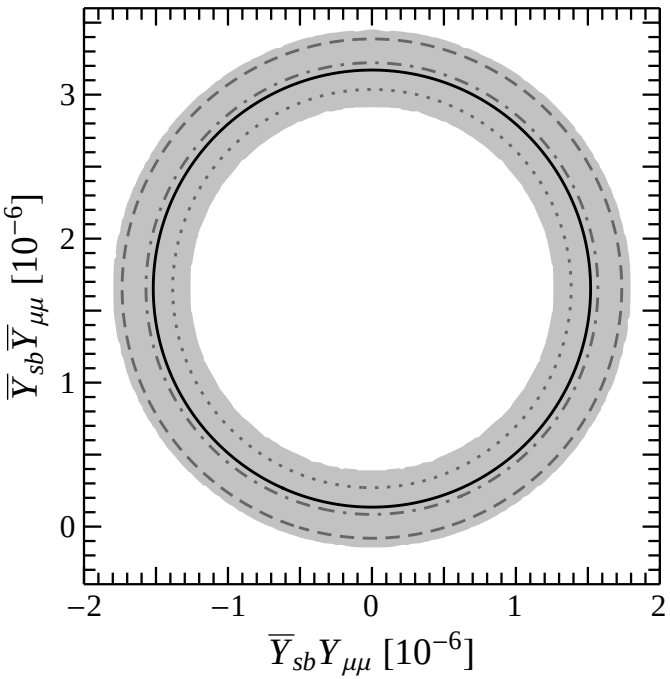
- Contributions from the Higgs FCNC

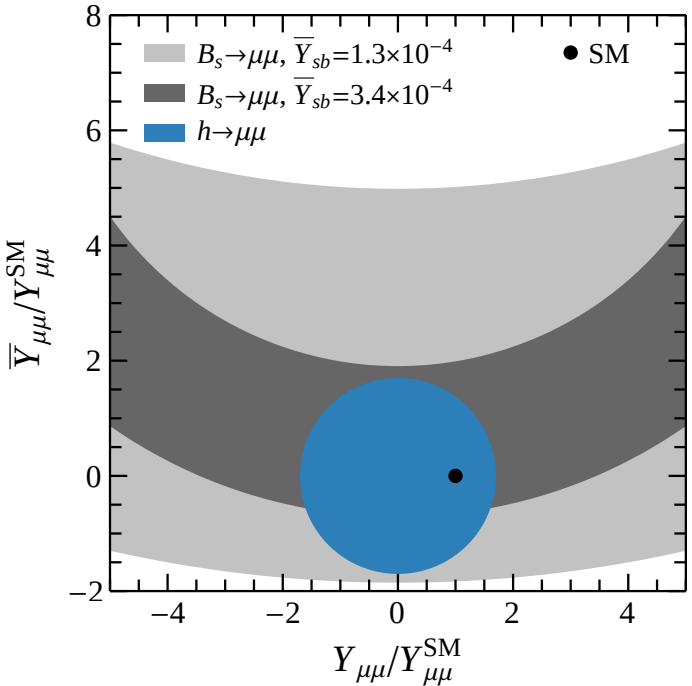
$\mathcal{B}$ depends on $(\bar Y_{sb}Y_{\mu\mu}, \bar Y_{sb}\bar Y_{\mu\mu})$

$$C_S^{\rm NP} = \kappa(Y_{sb} + i\bar Y_{sb})Y_{\mu\mu}, \quad C_P^{\rm NP} = i\kappa(Y_{sb} + i\bar Y_{sb})\bar Y_{\mu\mu}, \quad \kappa = \frac{\pi^2}{2G_F^2}\frac{1}{V_{tb}V_{ts}^*}\frac{1}{m_b m_\mu m_h^2}.$$

$$C'^{\rm NP}_S = \kappa(Y_{sb} - i\bar Y_{sb})Y_{\mu\mu}, \quad C'^{\rm NP}_P = i\kappa(Y_{sb} - i\bar Y_{sb})\bar Y_{\mu\mu},$$

Bounds from $B_s \to \mu^+\mu^-$





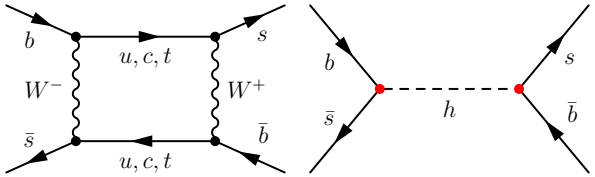
- 95% CL bound — Complex Y

  $$0.66 < \left|5.6 \times 10^5\, \bar{Y}_{sb} Y_{\mu\mu}\right|^2 + \left|1 - 6.0 \times 10^5\, \bar{Y}_{sb} \bar{Y}_{\mu\mu}\right|^2 < 1.26$$

- dark region: 95% CL allowed — Real Y
- black: exp central value
- dashed: $\mathcal{B}_{\rm exp}/\mathcal{B}_{\rm theo} = 1.1$
- dot-dashed: $\mathcal{B}_{\rm exp}/\mathcal{B}_{\rm theo} = 0.9$
- dotted: $\mathcal{B}_{\rm exp}/\mathcal{B}_{\rm theo} = 0.7$

- light gray: 95% CL allowed with $\bar{Y}_{sb} = 1.4 \times 10^{-4}$
- dark gray: 95% CL allowed with $\bar{Y}_{sb} = 3.4 \times 10^{-4}$
- blue: $\mu_{\mu\mu} < 2.8$ at 95% CL ATLAS Run I + II
- $|\bar{Y}_{sb}| = 3.4 \times 10^{-4}$: maximal value allowed by $B_s - \bar{B}_s$

$B_s - \bar{B}_s$ mixing



- Effective Hamiltonian

$$\mathcal{H}^{\Delta B=2} = \frac{G_F^2}{16\pi^2} m_W^2 (V_{tb}^* V_{ts})^2 \sum_i C_i \mathcal{O}_i + h.c..$$

- Effective operator

RGE: Buras et al. 2001

$$\mathcal{O}_1^{\rm VLL} = (\bar{b}^\alpha \gamma_\mu P_L s^\alpha)(\bar{b}^\beta \gamma^\mu P_L s^\beta), \qquad \mathcal{O}_1^{\rm LR} = (\bar{b}^\alpha \gamma_\mu P_L s^\alpha)(\bar{b}^\beta \gamma^\mu P_R s^\beta),$$

$$\mathcal{O}_1^{\rm VRR} = (\bar{b}^\alpha \gamma_\mu P_R s^\alpha)(\bar{b}^\beta \gamma^\mu P_R s^\beta), \qquad \mathcal{O}_2^{\rm LR} = (\bar{b}^\alpha P_L s^\alpha)(\bar{b}^\beta P_R s^\beta),$$

$$\mathcal{O}_1^{\rm SLL} = (\bar{b}^\alpha P_L s^\alpha)(\bar{b}^\beta P_L s^\beta), \qquad \mathcal{O}_2^{\rm SLL} = (\bar{b}^\alpha \sigma_{\mu\nu} P_L s^\alpha)(\bar{b}^\beta \sigma^{\mu\nu} P_L s^\beta),$$

$$\mathcal{O}_1^{\rm SRR} = (\bar{b}^\alpha P_R s^\alpha)(\bar{b}^\beta P_R s^\beta), \qquad \mathcal{O}_2^{\rm SRR} = (\bar{b}^\alpha \sigma_{\mu\nu} P_R s^\alpha)(\bar{b}^\beta \sigma^{\mu\nu} P_R s^\beta).$$

- Wilson coefficients from the Higgs FCNC

$$C_1^{\rm SLL,NP} = -\frac{1}{2}\kappa (Y_{bs} - i\bar{Y}_{bs})^2,$$

$$C_1^{\rm SRR,NP} = -\frac{1}{2}\kappa (Y_{bs} + i\bar{Y}_{bs})^2, \qquad \kappa = \frac{8\pi^2}{G_F^2}\frac{1}{m_h^2 m_W^2}\frac{1}{(V_{tb}^* V_{ts})^2},$$

$$C_2^{\rm LR,NP} = -\kappa (Y_{bs}^2 + \bar{Y}_{bs}^2),$$

$B_s - \bar{B}_s$ mixing

- Mass difference

$$\Delta m_s = 2|\langle \bar{B}_s|\mathcal{H}^{\Delta B=2}|B_s\rangle| = \frac{G_F^2}{8\pi^2} m_W^2 |V_{tb}^* V_{ts}|^2 \sum \left| C_i \langle \bar{B}_s \left| \mathcal{O}_i \right| B_s \rangle \right| ,$$

- SM prediction

$$\Delta m_s^{\rm SM} = (18.64^{+2.40}_{-2.27}) {\rm ps}^{-1}$$

- Exp data

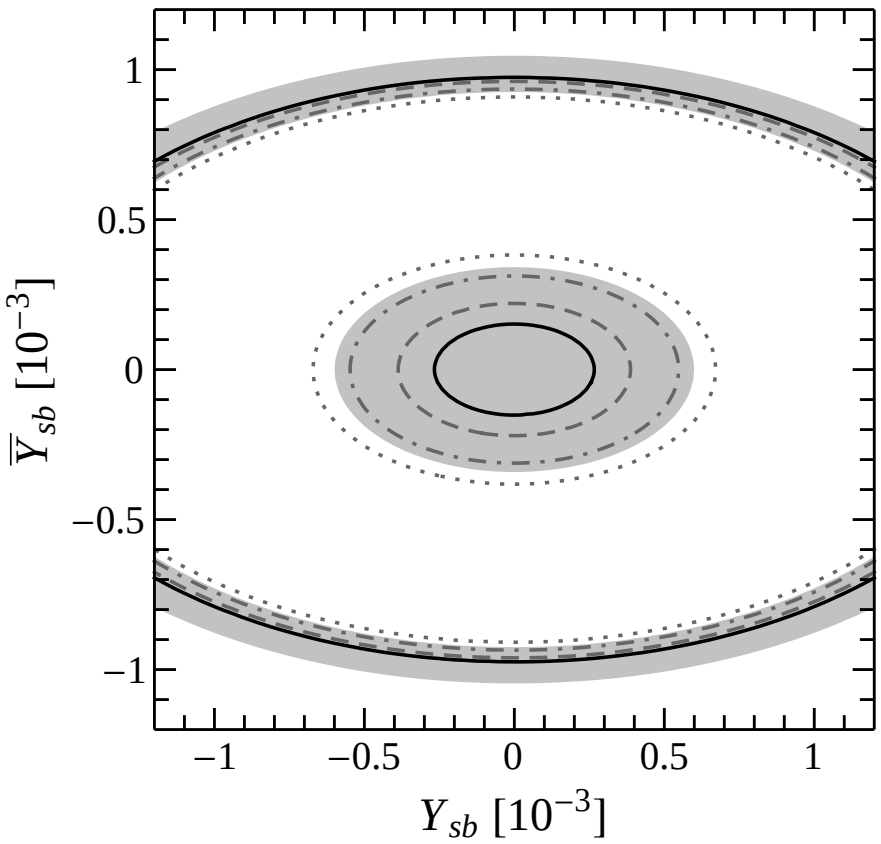
$$\Delta m_s^{\rm exp} = (17.757 \pm 0.021) {\rm ps}^{-1}$$

- 95% CL bound

complex Y

$$0.76 < \left| 1 - \left(0.7\, Y_{sb}^2 + 2.1\, \bar{Y}_{sb}^2 \right) \times 10^6 \right| < 1.29$$

Bounds from $B_s - \bar{B}_s$ mixing



- dark region: 95% CL allowed
- black: exp central value
- dashed: $\Delta m_s^{\rm exp}/\Delta m_s^{\rm theo} = 0.9$
- dot-dashed: $\Delta m_s^{\rm exp}/\Delta m_s^{\rm theo} = 0.8$
- dotted: $\Delta m_s^{\rm exp}/\Delta m_s^{\rm theo} = 0.7$

- constructive: $Y_{sb}, \bar{Y}_{sb} \sim 0$
- destructive: other

$h \to f_1 f_2$ decay

- Decay width $S = 1\ (1/2)$ for $f_1 \neq f_2\ (f_1 = f_2)$

$$\Gamma(h \to f_1 f_2) = S N_c \frac{m_h}{8\pi} \left(\left| Y_{f_1 f_2} \right|^2 + \left| \bar{Y}_{f_1 f_2} \right|^2 \right)$$

- $h \to \mu\tau$ $\sqrt{|Y_{\mu\tau}|^2 + |\bar{Y}_{\mu\tau}|^2} < 1.43 \times 10^{-3}$ at 95% CL

$$\mathcal{B}(h \to \mu\tau)_{\mathrm{CMS15}} = (0.84^{+0.39}_{-0.37})\%$$
$$\mathcal{B}(h \to \mu\tau)_{\mathrm{CMS17}} < 0.25\% \qquad \text{at 95\% CL}$$
$$\mathcal{B}(h \to \mu\tau)_{\mathrm{ATLAS16}} < 1.43\% \qquad \text{at 95\% CL}$$

Predictions

- Constraints
  - ▷ $\mathcal{B}(B_s \to \mu^+\mu^-)$ $(\bar{Y}_{sb}Y_{\mu\mu},\ \bar{Y}_{sb}\bar{Y}_{\mu\mu})$
  - ▷ Δm_s in $B_s - \bar{B}_s$ mixing $(Y_{sb},\ \bar{Y}_{sb})$
  - ▷ $\mathcal{B}(h \to \tau^+\tau^-)$ $(Y_{\tau\tau},\ \bar{Y}_{\tau\tau})$
  - ▷ $\mathcal{B}(h \to \mu\tau)$ $(Y_{\mu\tau},\ \bar{Y}_{\mu\tau})$
- Predictions
  - ▷ $h \to sb$

$$\Gamma(h \to sb) < 0.043 \text{ MeV} \quad \text{or} \quad \mathcal{B}(h \to sb) < 1.05\%$$

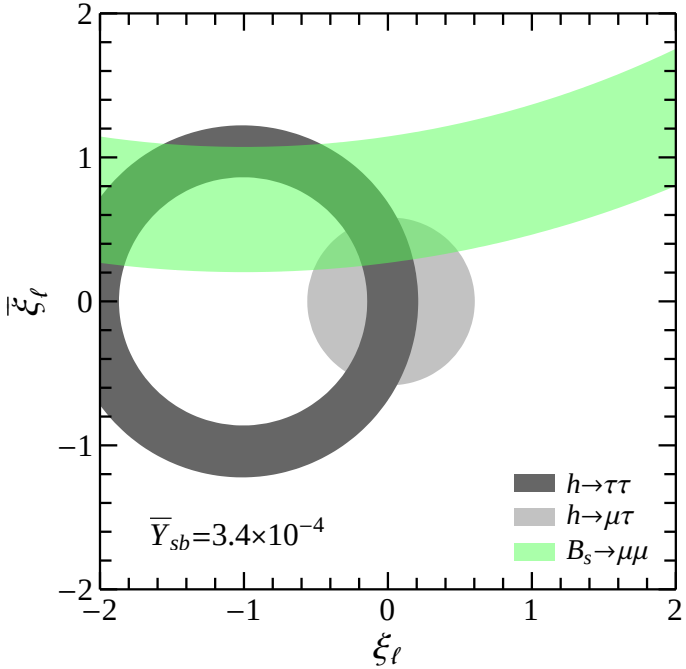
  - ▷ $B_s \to \tau\tau$ at $1\,\sigma$ (95%CL)

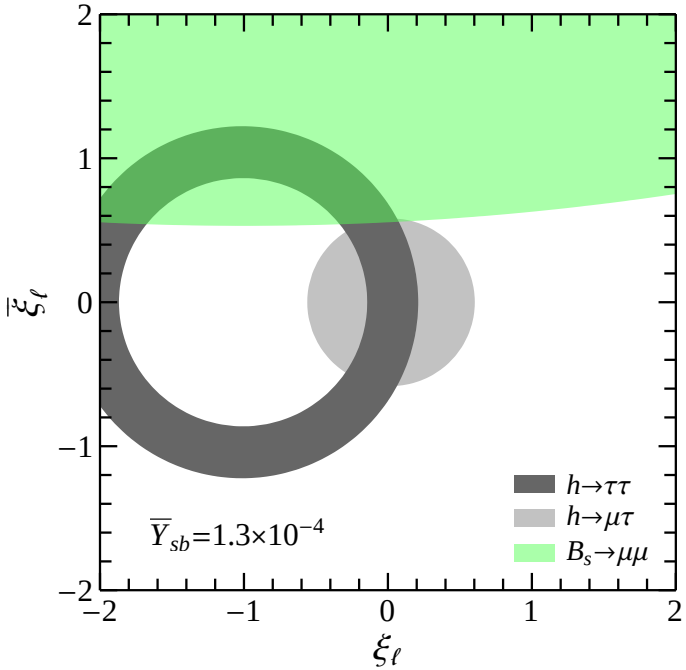
$$0.6\ (0.5) < \frac{\mathcal{B}(B_s \to \tau^+\tau^-)}{\mathcal{B}(B_s \to \tau^+\tau^-)_{\rm SM}} < 1.5\ (1.7)$$

  - ▷ $B_s \to \mu\tau$ at $1\,\sigma$ (95%CL)

$$\mathcal{B}(B_s \to \mu\tau) < 0.8\,(1.8)\ \times 10^{-8}$$

Bounds in the Cheng-Sher ansatz





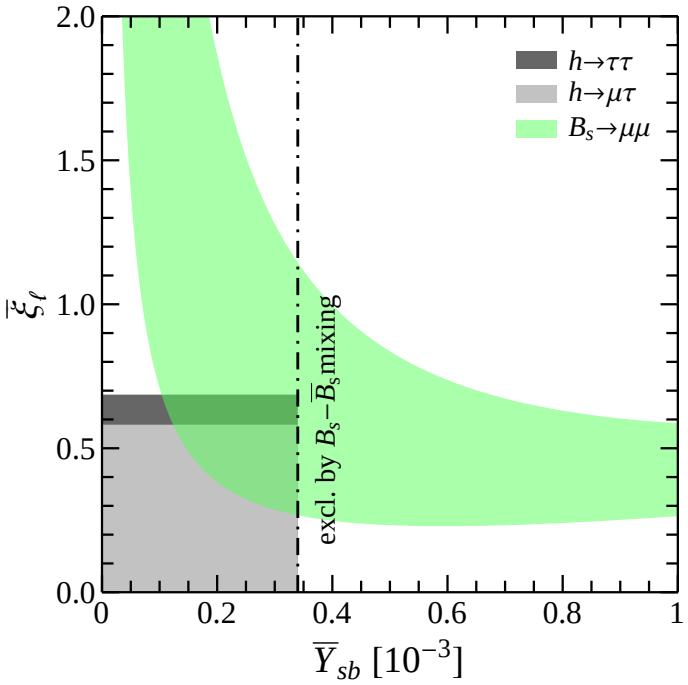
- Cheng-Sher ansatz

$$Y_{ij} = \delta_{ij}\frac{\sqrt{2}m_i}{v} + \xi_\ell\frac{\sqrt{2m_i m_j}}{v}, \quad \bar{Y}_{ij} = \bar{\xi}_\ell\frac{\sqrt{2m_i m_j}}{v}$$

- dark gray: 95% CL allowed, $h \to \tau\tau$
- light gray: 95% CL allowed, $h \to \mu\tau$
- green: $75\% < \dfrac{\mathcal{B}(B_s \to \mu^+\mu^-)}{\mathcal{B}(B_s \to \mu^+\mu^-)_{\rm SM}} < 95\%$

- lower bound on $\bar{Y}_{sb}$
- CP violation in $h \to \tau\tau$, $A_\pi \approx \pi/8$

Bounds in the Cheng-Sher ansatz: special case



- Cheng-Sher ansatz

$$Y_{ij} = \delta_{ij}\frac{\sqrt{2}m_i}{v} + \xi_\ell\frac{\sqrt{2m_i m_j}}{v}, \quad \bar{Y}_{ij} = \bar{\xi}_\ell\frac{\sqrt{2m_i m_j}}{v}$$

- special case: $\xi_\ell = 0$ and $Y_{sb} = 0$

- dark gray: 95% CL allowed, $h \to \tau\tau$
- light gray: 95% CL allowed, $h \to \mu\tau$
- green: $75\% < \dfrac{\mathcal{B}(B_s \to \mu^+\mu^-)}{\mathcal{B}(B_s \to \mu^+\mu^-)_{\rm SM}} < 95\%$

- lower bound on $\bar{Y}_{sb}$
- CP violation in $h \to \tau\tau$, $A_\pi \approx \pi/8$

Summary

- Motivated by the recent precision determination of the $B_s \to \mu^+\mu^-$ decay branching ratio, we consider its constraints on tree-level flavor-changing Yukawa couplings with the 125-GeV Higgs boson.
- For generally complex Yukawa couplings, the constraints on flavor-changing couplings are obtained:

$$0.66 < \left|5.6 \times 10^5\, \bar{Y}_{sb} Y_{\mu\mu}\right|^2 + \left|1 - 6.0 \times 10^5\, \bar{Y}_{sb} \bar{Y}_{\mu\mu}\right|^2 < 1.26 \ .$$
$$0.76 < \left|1 - \left(0.7\, Y_{sb}^2 + 2.1\, \bar{Y}_{sb}^2\right) \times 10^6\right| < 1.29 \ .$$

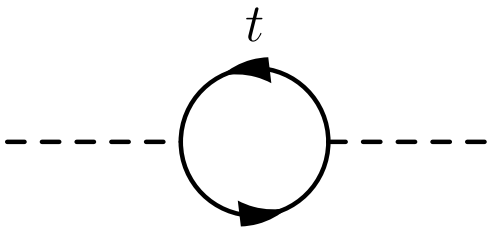
- For the Yukawa couplings in Cheng-Sher ansatz, We have shown that if the $B_s \to \mu^+\mu^-$ branching ratio is found to deviate significantly from the SM expectation in the future, the combined analysis with the $h \to \tau\tau$ and $\mu\tau$ data can give us a lower bound on the pseudoscalar Yukawa coupling $\bar{Y}_{sb}$. Simultaneously, CP violation in the $h \to \tau\tau$ decay could be large.

Thank You !

Backup

Higgs After the Discovery: 1. Hierarchy Problem

- If SM is an effective theory below Λ
- Higgs mass receives quadratically divergent radiative corrections

$\delta m_h^2 =$ 

$+ \ldots = \frac{c}{16\pi^2}\Lambda^2$

- Large cancellation

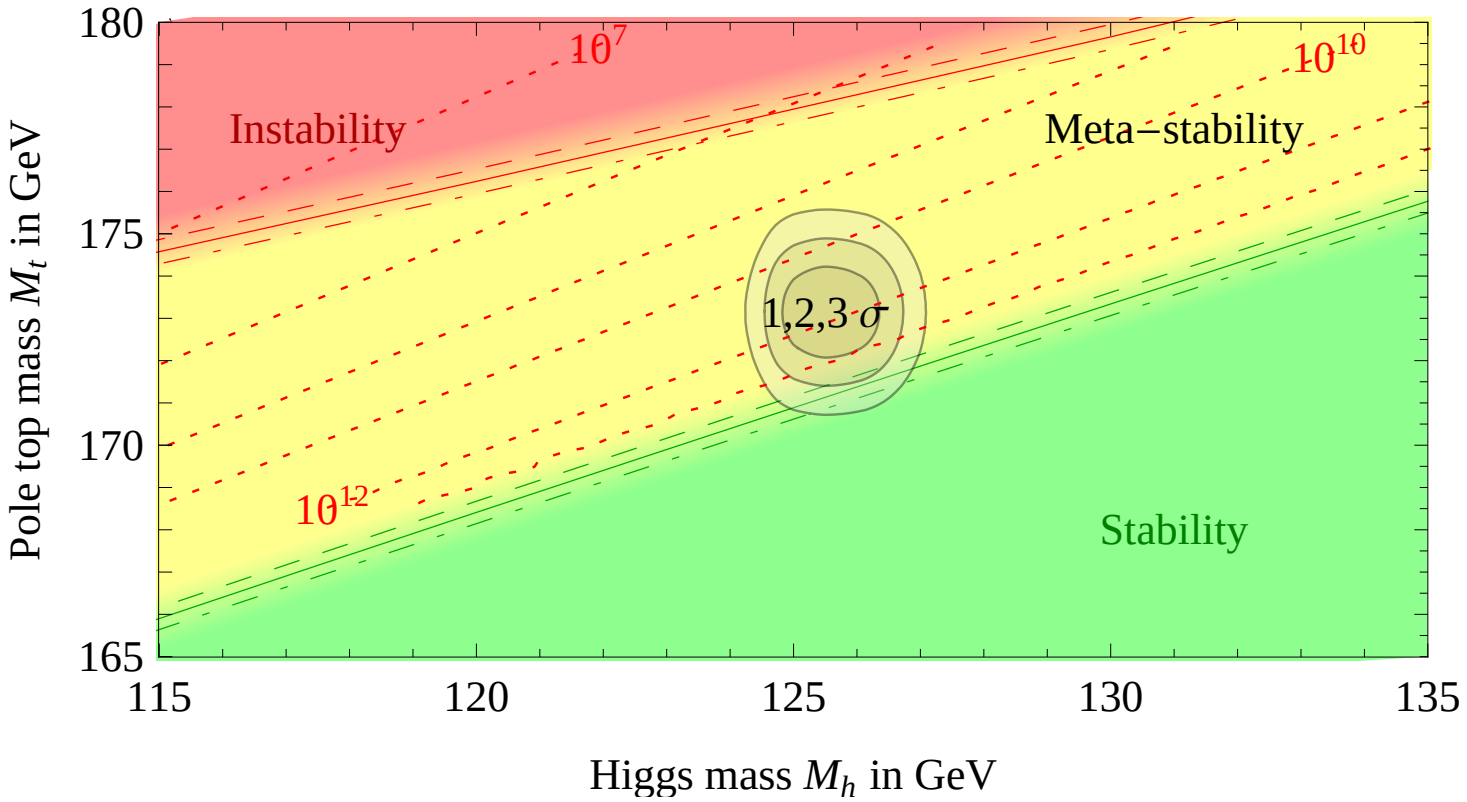
regularization independent

fine-tuning

$$m_h^2 = m_{h,0}^2 + \frac{c}{16\pi^2}\Lambda^2 = 126\,\mathrm{GeV}^2$$

- Possible answer: New Physics
  - ▷ SUSY
  - ▷ Extra Dimensions
  - ▷ Dynamical Symmetry Breaking
  - ▷ Compositeness
  - ▷ . . . . . .

Higgs After the Discovery: 2. Vacuum Stability

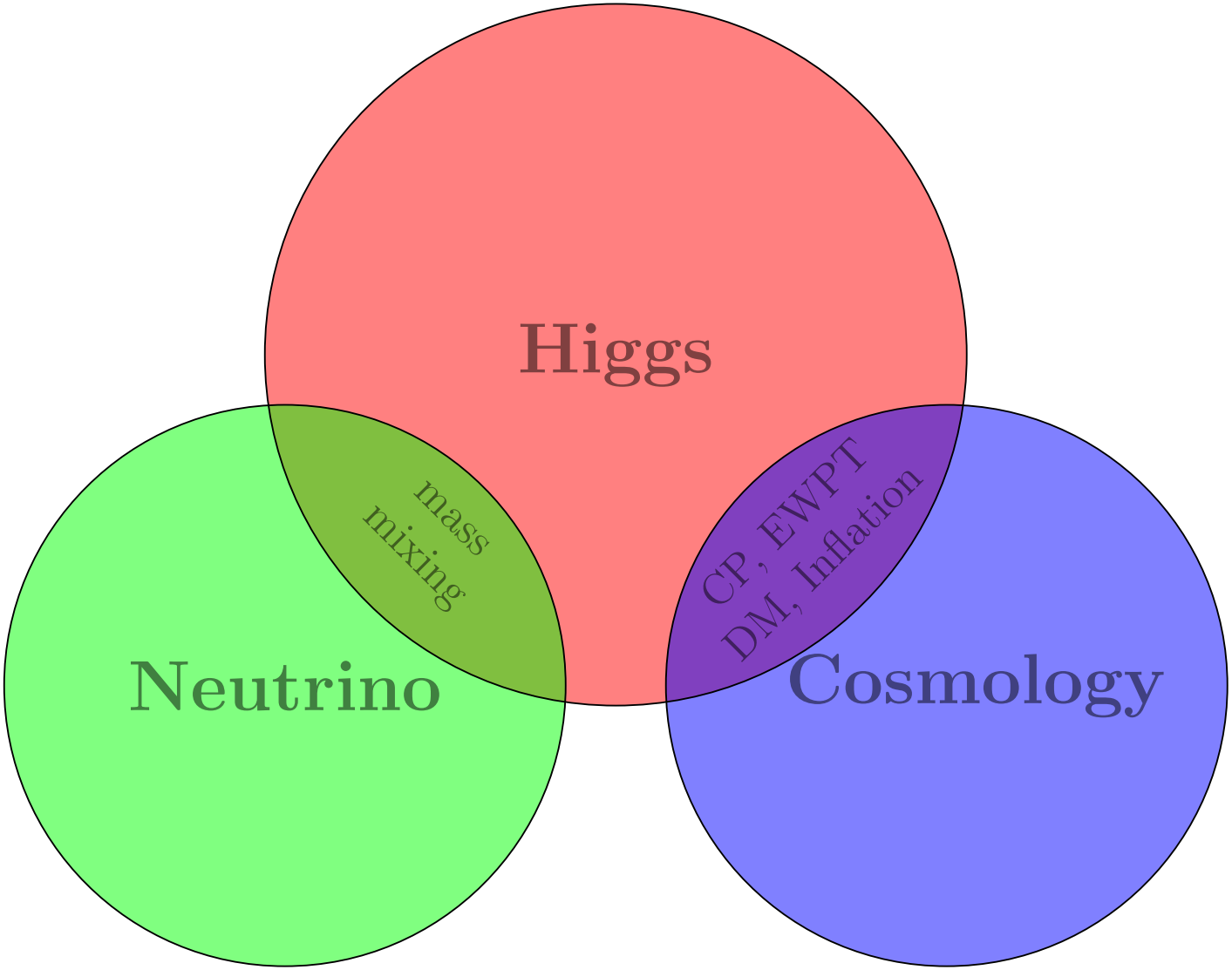


"While λ (Higgs quartic coupling) at the Planck scale is remarkably close to zero, absolute stability of the Higgs potential is excluded at 98% C.L. for $M_h < 126\,\mathrm{GeV}$."

G. Degrassi, et. al. JHEP 12

Why $\lambda \approx 0$ @ $\Lambda_{\mathrm{Planck}}$?

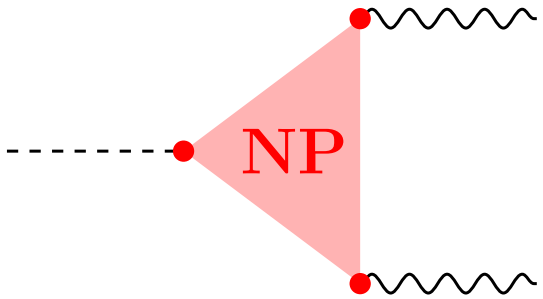
Higgs After the Discovery: 3. Related to BSM phenomena



Higgs: A Window to New Physics

- Precision measurement of the Higgs properties will be a central topic for the LHC Run II, its high-luminosity upgrade, and other planed high-energy colliders.

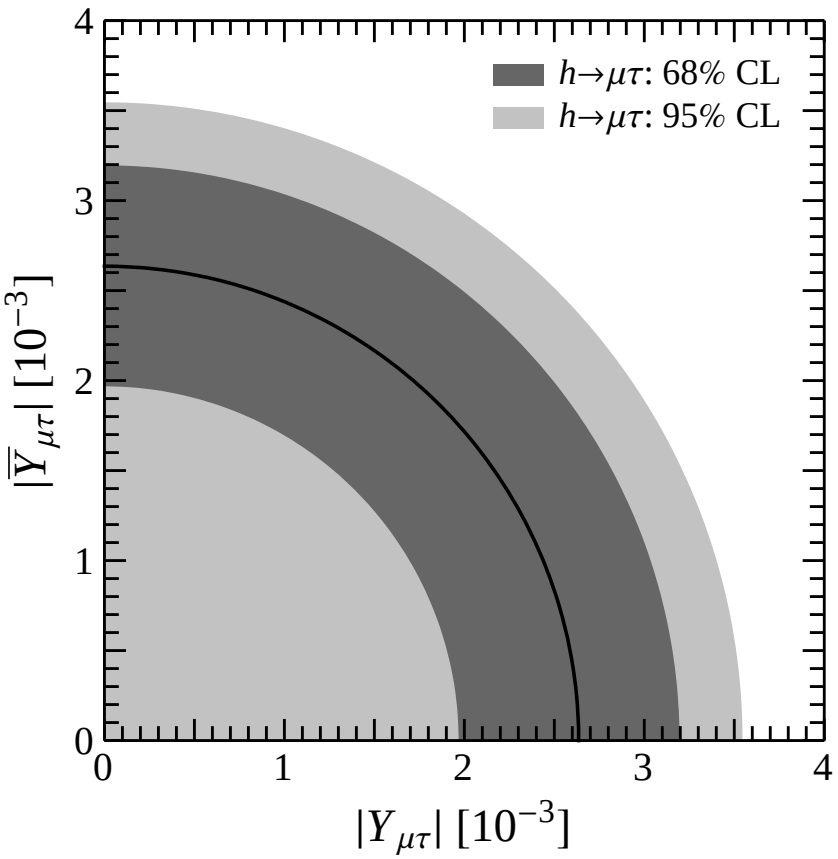
- Precision Higgs coupling measurements are important as an indirect search for New Physics. The SM precisely predicts all the Higgs couplings to fermion and gauge boson. Any deviation from these predictions will provide a clear evidence for New Physics beyond the SM.



Constraints and Predictions

- Constraints
  - $\mathcal{B}(B_s \to \mu^+\mu^-)$ $(\bar{Y}_{sb}Y_{\mu\mu},\ \bar{Y}_{sb}\bar{Y}_{\mu\mu})$
  - Δm_s in $B_s - \bar{B}_s$ mixing $(Y_{sb},\ \bar{Y}_{sb})$
  - $\mathcal{B}(h \to \tau^+\tau^-)$ $(Y_{\tau\tau},\ \bar{Y}_{\tau\tau})$
  - $\mathcal{B}(h \to \mu\tau)$ $(Y_{\mu\tau},\ \bar{Y}_{\mu\tau})$
- Predictions
  - $\mathcal{B}(B_s \to \mu\tau)$
  - $\mathcal{B}(B_s \to \tau^+\tau^-)$
- With particular Yukawa texture
  - Cheng-Sher Ansatz
  - Minimal Flavour Violation

Bounds from $h \to \mu\tau$



- black region: 95% CL allowed
- gray region: 68% CL allowed
- black line: data central value
- data at the LHC (CMS)

$\mathcal{B} = (0.84^{+0.39}_{-0.37})\%$ 19.7fb^{-1}

$\mathcal{B} < 0.25\%$ 35.9fb^{-1}

$B_s \to \mu^+\mu^-$ decay: SM and exp

- SM prediction

Bobeth et al. 2013, with updated inputs

$$\overline{\mathcal{B}}(B_s \to \mu^+\mu^-)_{\rm SM} = \big(3.44 \pm 0.19\big) \times 10^{-9}$$

- Exp data

$$\overline{\mathcal{B}}(B_s \to \mu^+\mu^-)_{\rm LHCb2017} = \big(3.0 \pm 0.6^{+0.3}_{-0.2}\big) \times 10^{-9}$$
$$\overline{\mathcal{B}}(B_s \to \mu^+\mu^-)_{\rm CMS2013} = \big(3.0^{+1.0}_{-0.9}\big) \times 10^{-9}$$
$$\overline{\mathcal{B}}(B_s \to \mu^+\mu^-)_{\rm avg.} = \big(3.0 \pm 0.5\big) \times 10^{-9}$$

- Consistent within 1σ. We can use it to constrain possible NP effects.
- However, experimental central value is $\sim 13\%$ lower than the SM one. NP effects may address such a discrepancy, though the error bars are still too large to call for such a solution.