MONASH University

LFV in $h \to \mu\tau$ and

CP violation in $h \to \tau\tau$

FLASY 2016, Valparaiso Chile

based on:

Alper Hayreter, Xiao-Gang He, G. Valencia PLB760 (2016)

Alper Hayreter, Xiao-Gang He, G. Valencia arXiv:1606.00951 (PRD)

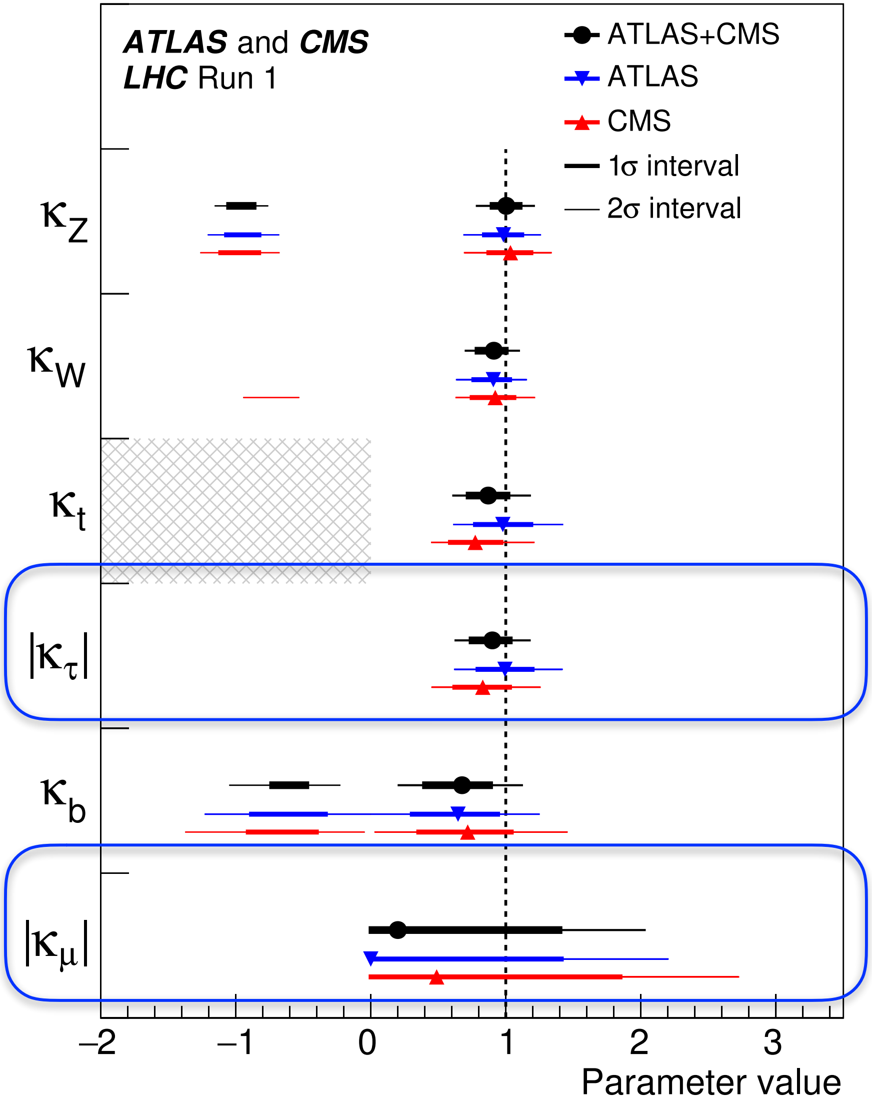
German Valencia

GROUP OF EIGHT AUSTRALIA

LFV and CPV in h fermion couplings

- LHC is testing the higgs couplings to fermions in detail, looking for deviations from the SM
- deviations can take the form
  - Yukawa couplings not matching SM prediction (mass)
  - new couplings not present in SM
- beyond SM it is very common to get
  - tree level FCNC
  - lepton flavor violation
  - CP violation (multiple scalars/pseudoscalars)
- correlate different observables including B physics

higgs couplings at LHC



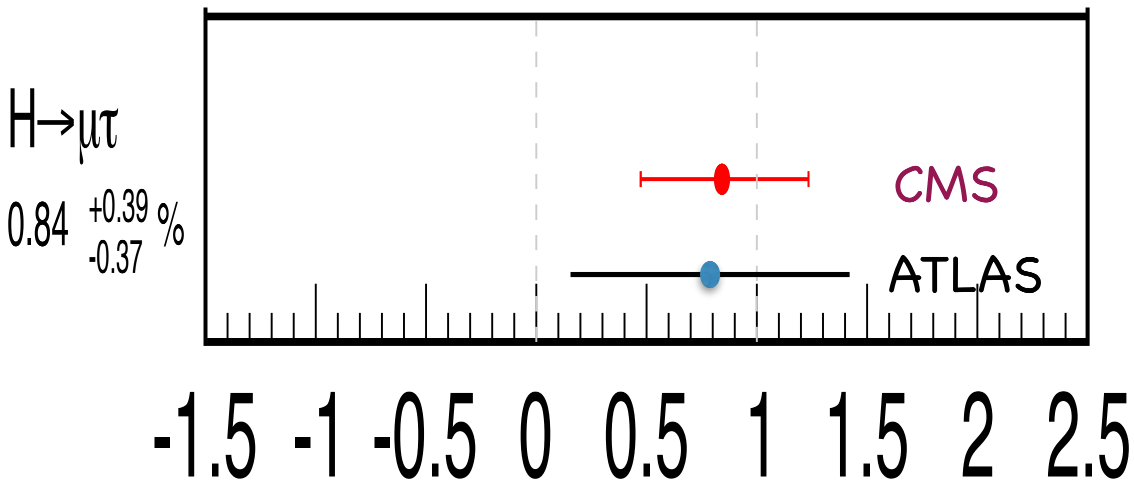
ATLAS and CMS Collaborations (Georges Aad *et al.*). JHEP 1608 (2016) 045

$$B(h \to e^+e^-) < 0.0019 (95\% \text{c.l.})$$
$$= 3.7 \times 10^5 \times B(h \to e^+e^-)_{SM}$$

CMS Collaboration (Vardan Khachatryan *et al.*). Phys.Lett. B744 (2015) 184-207

higgs LFV: h → $\tau\mu$?

- two years ago CMS-HIG-14-005:



- very exciting for theorists
  - about half of possible operators ruled out by Z LFV
  - CMS Phys.Lett. B749 (2015) 337-362, ATLAS arXiv 1508.03372

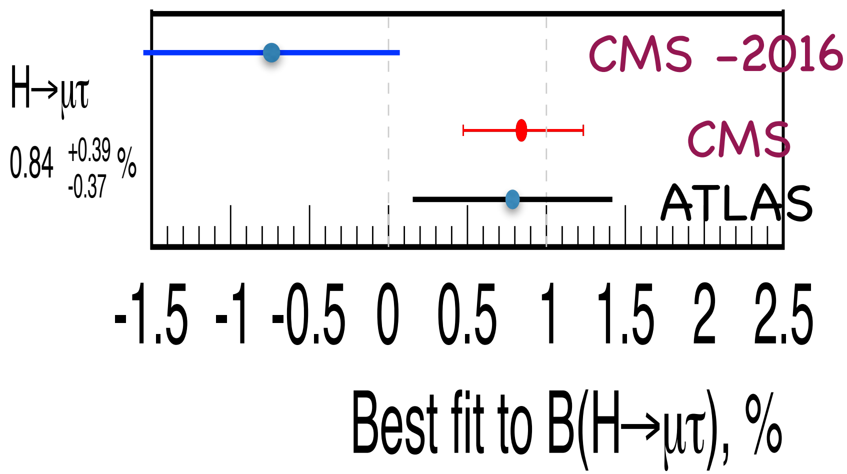
too good to last?

- this year:

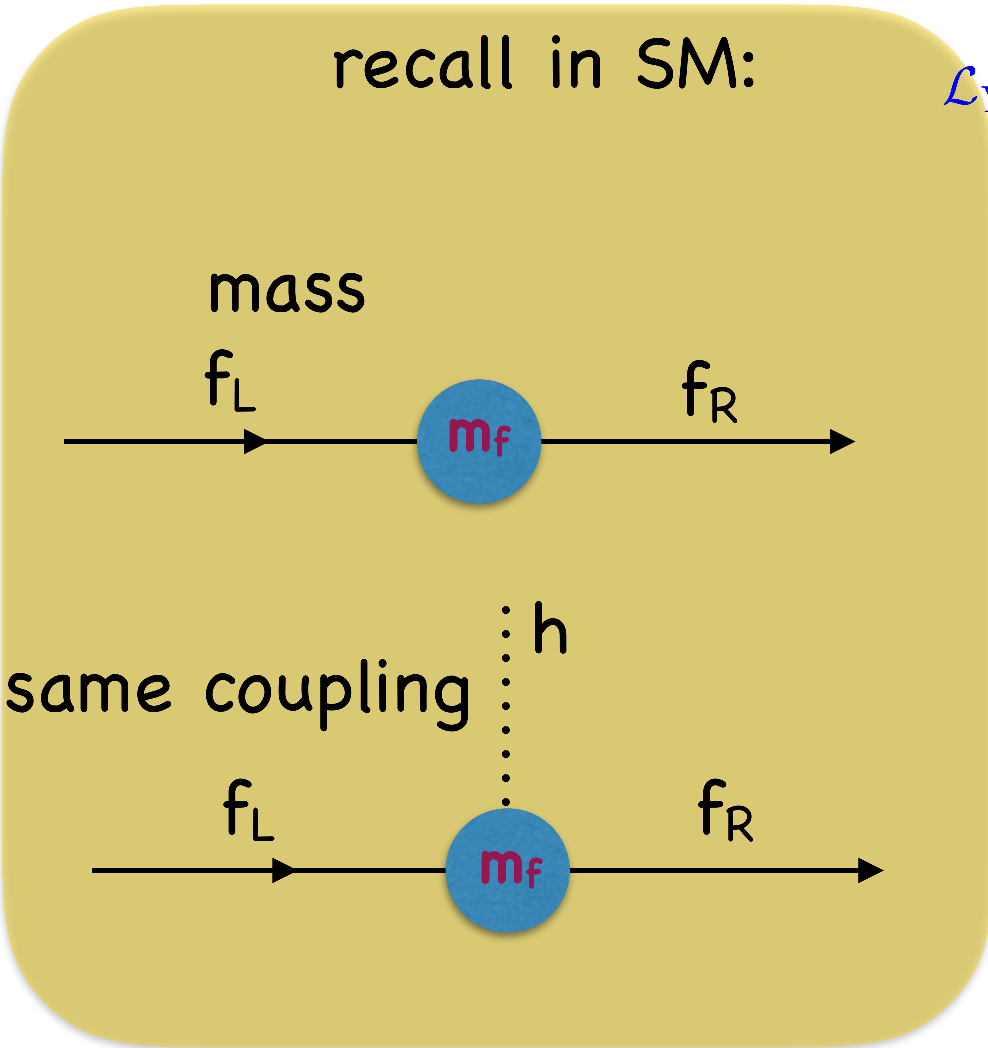
- CMS PAS HIG-16-005 (seems to have disappeared, of course)

$$B(H \to \mu\tau) = (-0.76^{+0.81}_{-0.84})\%$$

- but still $B(H \to \mu\tau) < 1.2\ \%$ at 95%cl



Yukawa's in SM: no LFV no CP violation



$$\mathcal{L}_Y = -y_{ij}\bar{\ell}_{Li}\, e_{Rj}\phi + \text{ h.c.}$$

$$\langle\phi\rangle = v/\sqrt{2}$$

$$= -\left(1+\frac{h}{v}\right)\frac{y_{ij}v}{\sqrt{2}}\bar{e}_{Li}\, e_{Rj} + \text{ h.c.}$$

$$S_e^\dagger(vy_{ij}/\sqrt{2})T_e = m_i\delta_{ij}$$ diagonal

$$= -\left(1+\frac{h}{v}\right)m_i\bar{e}_i\, e_i\ .$$

real

Yukawa's beyond SM: LFV and CP violation

$$\mathcal{L}_Y = -y_{ij}\bar{\ell}_{Li}\, e_{Rj}\phi + \text{ h.c.}$$

add correction to Yukawa

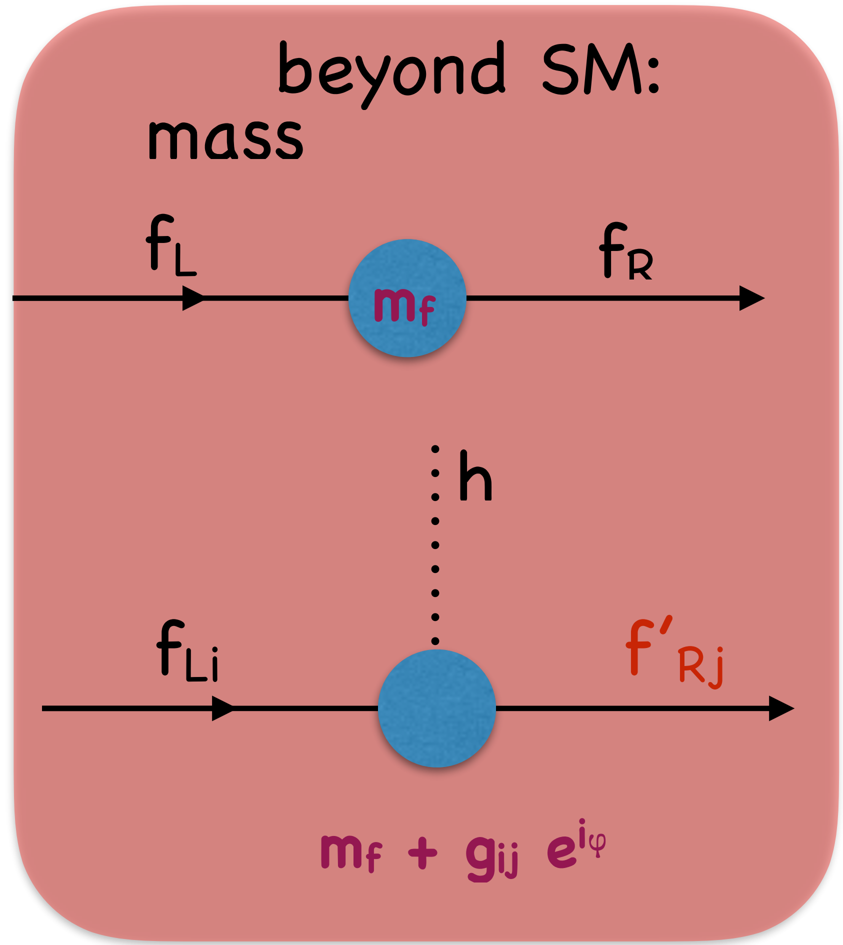
$$+ \quad -\frac{g_{ij}}{\Lambda^2}\,(\phi^\dagger\phi)\bar{\ell}_{Li}\, e_{Rj}\ \phi + \text{ h.c.}$$

$$= \quad -\left(1+\frac{h}{v}\right)\frac{y_{ij}v}{\sqrt{2}}\bar{e}_{Li}\ e_{Rj}$$

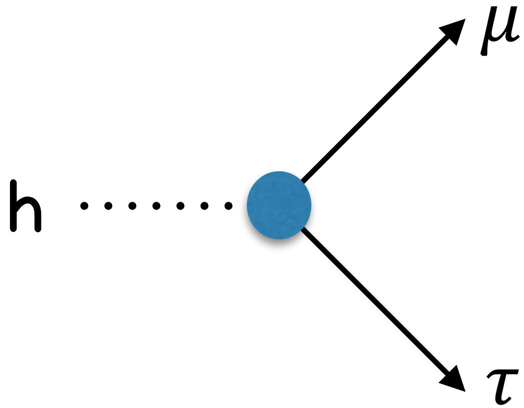
$$- \quad \frac{v^2}{2\Lambda^2}\left(1+\frac{3h}{v}\right)\frac{g_{ij}v}{\sqrt{2}}\bar{e}_{Li}\ e_{Rj} + \text{ h.c.}$$

$$\left(S_e^\dagger \frac{v}{\sqrt{2}}(y+\frac{v^2}{2\Lambda^2}g)T_e\right)_{ij} = m_i\delta_{ij}$$

$$\left(S_e^\dagger \frac{1}{\sqrt{2}}(y+\frac{3v^2}{2\Lambda^2}g)T_e\right)_{ij} = \frac{m_i}{v}\delta_{ij} + \frac{v^2}{\sqrt{2}\Lambda^2}(S_e^\dagger g T_e)_{ij}$$



h → $\tau\mu$ and CP violation in h → $\tau\tau$

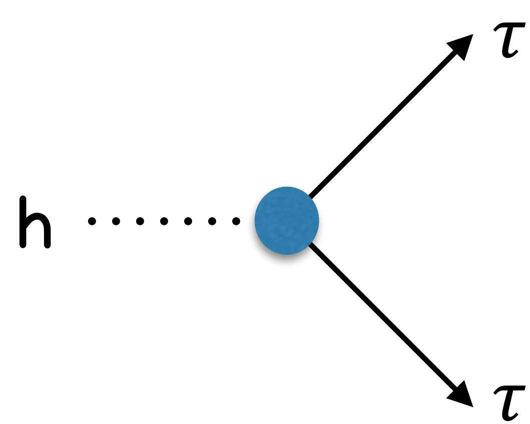


how can we relate them?

$$-\frac{m_\tau}{v} h \bar{\tau} \left(1 + \epsilon_\tau + i\tilde{r}_\tau \gamma_5\right) \tau$$

$$B(h \to \mu\tau) < 1.2\%$$

$$\sqrt{g_{h\tau\mu}^2 + g_{h\mu\tau}^2} < 3.16 \times 10^{-3}$$



also have:

$$\kappa_\tau = \sqrt{(1+\epsilon_\tau)^2 + \tilde{r}_\tau^2} = 0.90^{+0.14}_{-0.13}$$
$$\kappa_\mu = \sqrt{(1+\epsilon_\mu)^2 + \tilde{r}_\mu^2} = 0.2^{+1.2}_{-0.2}$$
$$\kappa_e = \sqrt{(1+\epsilon_e)^2 + \tilde{r}_e^2} \leq 611$$

texture of mass matrix corrections

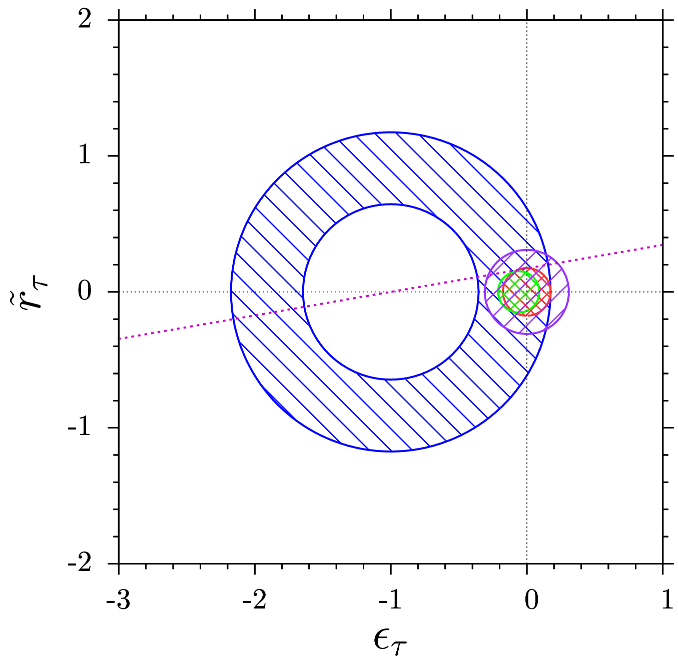
democratic

$$(S_e^\dagger g T_e)_{ij} \sim \lambda^e_{1,2} \sim \begin{pmatrix} 1 & 1 & 1 \\ 1 & 1 & 1 \\ 1 & 1 & 1 \end{pmatrix}$$

hierarchical: Cheng-Sher ansatz

$$(S_e^\dagger g T_e)_{ij} \sim \lambda^e_{1,2} \sim \begin{pmatrix} m_e & \sqrt{m_e m_\mu} & \sqrt{m_e m_\tau} \\ \sqrt{m_e m_\mu} & m_\mu & \sqrt{m_\mu m_\tau} \\ \sqrt{m_e m_\tau} & \sqrt{m_\mu m_\tau} & m_\tau \end{pmatrix} .$$

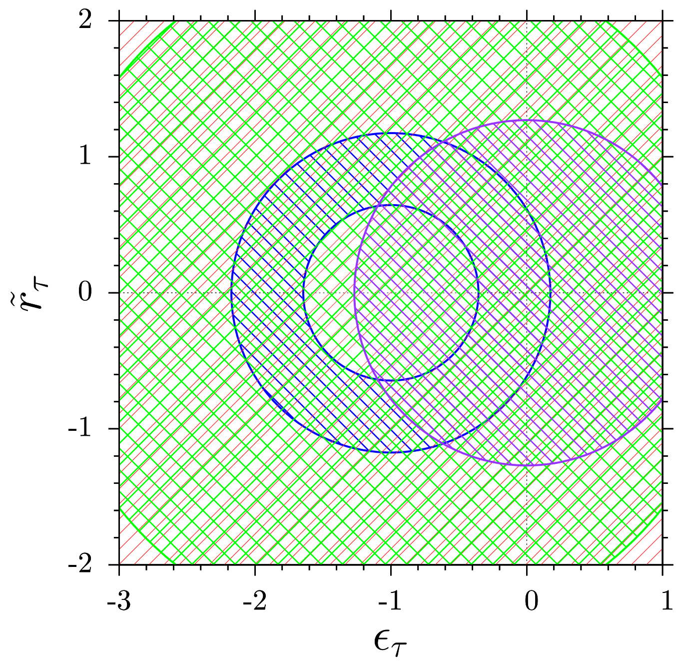
democratic corrections



$$\left| \frac{r_\tau \tilde{r}_\tau}{r_\tau^2 + \tilde{r}_\tau^2} \right| \leq 0.15.$$

Region of parameter space allowed at the 95% c.l. The blue region is from the $h \to \tau\tau$ rate, the green region from the $h \to \mu\mu$ limit, the red region is from the $h \to ee$ limit and the purple region is from the CMS $h \to \tau\mu$ upper bound.

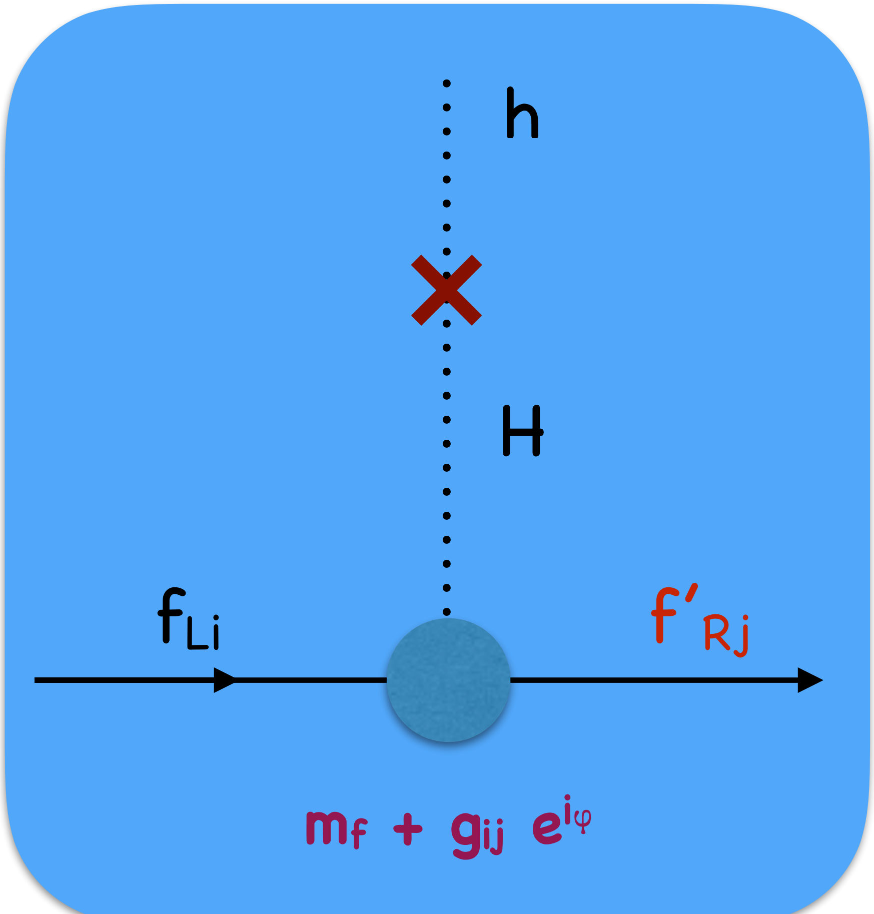
hierarchical corrections



$$\left| \frac{r_\tau \tilde{r}_\tau}{r_\tau^2 + \tilde{r}_\tau^2} \right| \leq 0.5.$$

Region of parameter space allowed at the 95% c.l. The blue region is from the $h \to \tau\tau$ rate, the green region from the $h \to \mu\mu$ limit, the red region is from the $h \to ee$ limit and the purple region is from the CMS $h \to \tau\mu$ upper bound.

An explicit model with more scalars



- LFV possible if H has LFV couplings
- not in type I, II 2HDM
- possible in type III

- Look at two models that single out the third generation introduced to address other anomalies
- CP violation is not automatic

Model I: SU(2)$_l$xSU(2)$_h$xU(1)$_Y$

- a separate SU(2) for the third generation `top-flavor'
- much phenomenology, here we only care about Yukawas
- fermions:

$$Q_L^{1,2} : (3,2,1,1/3)\ ,\quad Q_L^3 : (3,1,2,1/3)\ ,$$
$$U_R^{1,2,3} : (3,1,1,4/3)\ ,\quad D_R^{1,2,3} : (3,1,1,-2/3)\ ,$$
$$L_L^{1,2} : (1,2,1,-1)\ ,\quad L_L^3 : (1,1,2,-1)\ ,\quad E_R^{1,2,3} : (1,1,1,-2)\ ,$$

- SB: $\underbrace{SU(2)_l \times SU(2)_h}_{SU(2)_L} \times U(1)_Y$

$SU(2)_L \quad \eta : (1,2,2,0),\ <\eta>= u \sim \text{TeV}$

- SM and fermion masses

$\Phi_1 : (1,2,1,1),\ \Phi_2 : (1,1,2,1)$

$<\Phi_i>= v_i,\quad v_1^2 + v_2^2 = v^2$

- choose $v_2 >> v_1$
  - reduce hierarchy of Yukawa matrix

Yukawas

$$\mathcal{L}_{\rm Y} = f^u_{ij}\bar{u}_{iR}\tilde{\Phi}_1^\dagger Q_{jL} + g^u_{i3}\bar{u}_{iR}\tilde{\Phi}_2^\dagger Q_{3L} + f^d_{ij}\bar{d}_{iR}\Phi_1^\dagger Q_{jL} + g^d_{i3}\bar{d}_{iR}\Phi_2^\dagger Q_{3L}$$
$$+ \quad f^e_{ij}\bar{E}_{iR}\Phi_1^\dagger L_{jL} + g^e_{i3}\bar{E}_{iR}\Phi_2^\dagger L_{3L} + \text{h.c.}\ ,$$

$$M^e = \frac{1}{\sqrt{2}}(v_1\lambda_1^e + v_2\lambda_2^e) = \frac{v}{\sqrt{2}}(s_\beta\lambda_1^e + c_\beta\lambda_2^e)$$

which leads to: $\mathcal{L}_{\rm Y} = -\bar{e}_L\left(\hat{M}^e(1+\frac{h}{v}) + \lambda^e(H^0 - iA^0)\right)e_R + \text{h.c.}$

$$\lambda^e = S_e^\dagger(\lambda_1^e - \lambda_2^e)T_e = -\frac{\sqrt{2}}{vc_\beta}\hat{M}^e + (1+\frac{s_\beta}{c_\beta})S_e^\dagger\lambda_1^e T_e = \frac{\sqrt{2}}{vs_\beta}\hat{M}^e - (1+\frac{c_\beta}{s_\beta})S_e^\dagger\lambda_2^e T_e$$

$$\lambda_1^e = \begin{pmatrix} f^{e*}_{11} & f^{e*}_{21} & f^{e*}_{31} \\ f^{e*}_{12} & f^{e*}_{22} & f^{e*}_{32} \\ 0 & 0 & 0 \end{pmatrix}, \quad \lambda_2^e = \begin{pmatrix} 0 & 0 & 0 \\ 0 & 0 & 0 \\ g^{e*}_{13} & g^{e*}_{23} & g^{e*}_{33} \end{pmatrix}.$$

with a possible pattern of `suppressed' LFV couplings

couplings of lightest scalar

with mixing (potential is CP conserving)

$$\begin{pmatrix} h \\ H \end{pmatrix} = \begin{pmatrix} \cos\alpha & -\sin\alpha \\ \sin\alpha & \cos\alpha \end{pmatrix} \begin{pmatrix} h^{m_1} \\ h^{m_2} \end{pmatrix}.$$

in the Higgs mass eigenstate basis, the lightest one

$$\mathcal{L}_{hee} = -\bar{e}_L \left(\frac{\hat{M}^e}{v} \cos\alpha + \lambda^e \sin\alpha \right) e_R h^{m_1} + \text{h.c.}$$

it has LFV couplings, but no CPV

From $M^e = S_e \hat{M}^e T_e^\dagger$, we have $(M^e T_e)_{33} = (S_e \hat{M}^e)_{33}$ which leads to

$$c_\beta \frac{v}{\sqrt{2}} (T_{e13} g_{13}^{e*} + T_{e23} g_{23}^{e*} + T_{e33} g_{33}^{e*}) = m_\tau S_{e33}$$

$$(S_e^\dagger \lambda_2^e T_e)_{33} = (T_{e13} g_{13}^{e*} + T_{e23} g_{23}^{e*} + T_{e33} g_{33}^{e*}) S_{e33}^* = \frac{\sqrt{2}}{v c_\beta} m_\tau |S_{e33}|^2$$

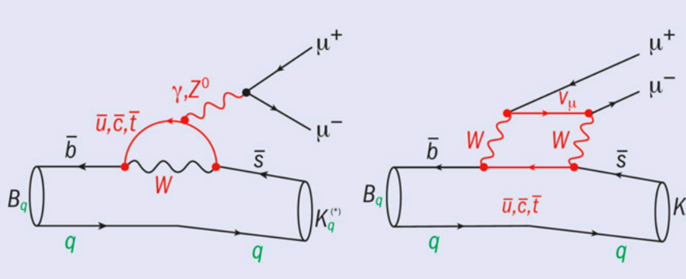
Since m_τ is normalized to be real, so is $(S_e^\dagger \lambda_2 T_e)_{33}$.

Lepton universality in neutral currents ?

Lepton universality: $R_K = BF(B^+ \to K^+\mu^+\mu^-) / BF(B^+ \to K^+e^+e^-)$

PRL 113 (2014) 151601

George Lafferty
Manchester and CERN



- LHCb has measured the ratio of branching fractions
  - $R_K = BF(B^+ \to K^+ \mu^+ \mu^-) / BF(B^+ \to K^+ e^+ e^-)$

SM prediction $R_K = 1.0003 \pm 0.0001$ (Bobeth et. al., JHEP 0712, 040 (2007))

$$R_K(\text{LHCb},\ 1 < q^2 < 6\,\text{GeV}^2/c^4) = 0.745^{+0.090}_{-0.074} \pm 0.036$$

- The LHCb measurements is 2.6σ from the SM prediction

George Lafferty
Manchester and CERN

Conference on New Physics at the
Large Hadron Collider

New Z′

$$R_K = 0.745 \Rightarrow \begin{cases} \frac{\mathcal{B}(B\to K\tau\bar{\tau})}{\mathcal{B}(B\to K\mu\bar{\mu})} = 1.36 \\ \frac{\mathcal{B}(B\to K(e\bar{\tau},\tau\bar{e}))}{\mathcal{B}(B\to K\mu\bar{\mu})} = 0.037 \end{cases}$$

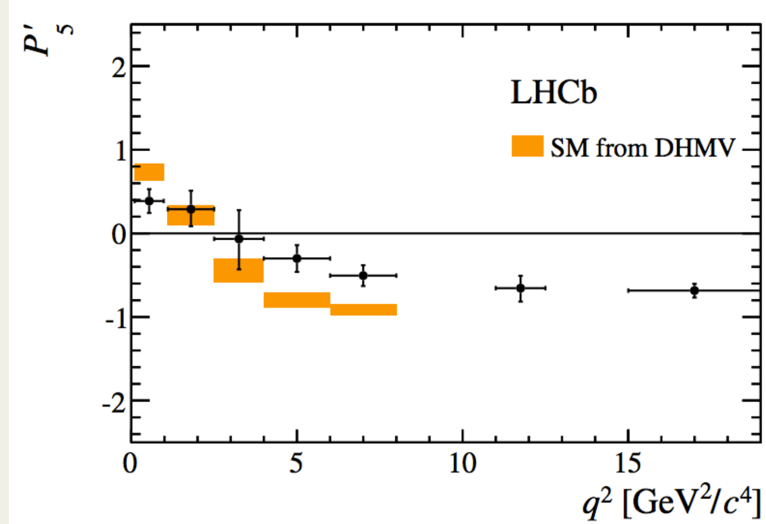
Other anomalies in the same modes

Angular analysis of $B^0 \to K^{*0}\mu^+\mu^-$ decays

JHEP 02 (2016) 104

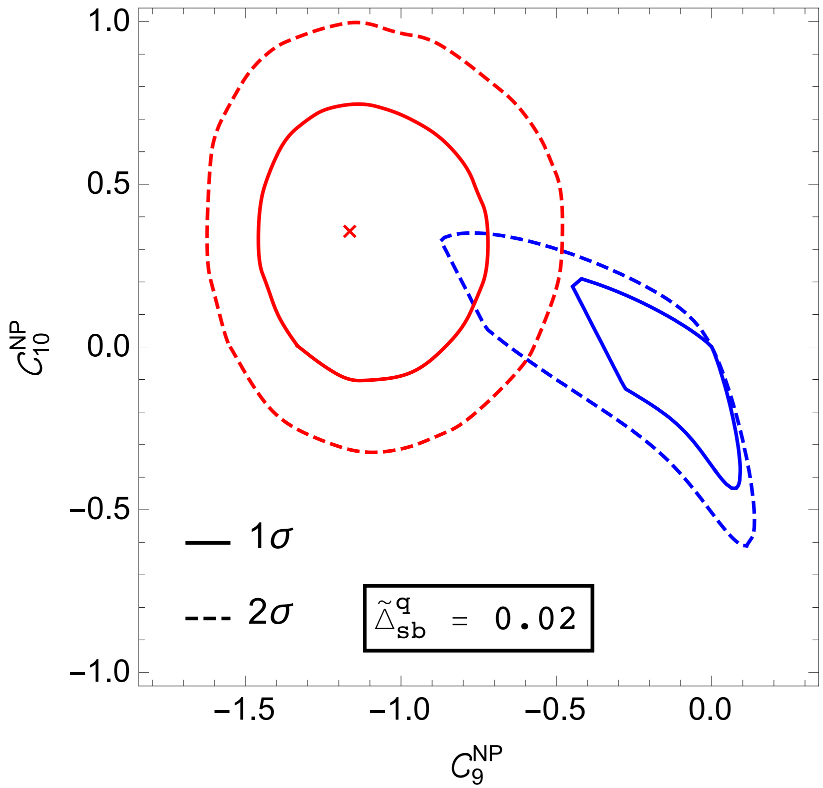
- Distributions of the observables are largely compatible with the SM predictions, apart from P_5'
- Local deviations of 2.8σ and 3.0σ
- Can be accommodated by modifying the real part of the vector coupling strength of the decays, $\Re(C_9)$
  - Requires a shift from SM value corresponding to 3.4σ
  - A lot of theory work ongoing to better understand this effect
  - Is it new physics (e.g. a new vector particle) or an unexpectedly large hadronic effect?

"DHMV" SM predictions from
S. Descotes-Genon et al., JHEP 12, 125 (2014)



top-flavour vs b→sℓℓ anomalies

Cheng-Wei Chiang, Xiao-Gang He, G. V., Phys.Rev. D93 (2016) no.7, 074003



The region allowed by the electroweak precision data fit and B_s mixing is shown in blue. The region allowed by a global analysis of b→sℓℓ observables by Descotes-Genon, Hofer, Matias, Virto JHEP 1606 (2016) 092 is shown in red

Model 2: $SU(3)_c \times SU(2)_L \times SU(2)_R \times U(1)_{B-L}$

- the third generation has an additional $SU(2)_R$
- fermion content

$$Q_L^{1,2,3} : (3,2,1,1/3)\ ,\quad Q_R^3 : (3,1,2,1/3)\ ,$$
$$U_R^{1,2} : (3,1,1,4/3)\ ,\quad D_R^{1,2} : (3,1,1,-2/3)\ ,$$
$$L_L^{1,2,3} : (1,2,1,-1)\ ,\quad L_R^3 : (1,1,2,-1)\ ,$$
$$E_R^{1,2} : (1,1,1,-2)\ ,\quad \nu_R^{1,2} : (1,1,1,0)\ .$$

- scalar content: H_R breaks $SU(2)_R$, H_L or ϕ breaks $SU(2)$ to SM … both needed to give all fermions mass

$$H_L = \begin{pmatrix} \frac{1}{\sqrt{2}}(v_L + h_L + iA_L) \\ h_L^- \end{pmatrix} : (1,2,1,-1)\ ,$$
$$H_R = \begin{pmatrix} \frac{1}{\sqrt{2}}(v_R + h_R + iA_R) \\ h_R^- \end{pmatrix} : (1,1,2,-1)\ ,$$
$$\phi = \begin{pmatrix} \frac{1}{\sqrt{2}}(v_1 + h_1 + ia_1) & h_2^+ \\ h_1^- & \frac{1}{\sqrt{2}}(v_2 + h_2 + ia_2) \end{pmatrix} : (1,2,2,0)\ .$$

Yukawas

$$\mathcal{L}_{\rm Y} = - \left(\bar{Q}_L^{1,2,3}\lambda_L^u H_L U_R^{1,2} + \bar{Q}_L^{1,2,3}\lambda_L^d \tilde{H}_L D_R^{1,2} + \bar{Q}_L^{1,2,3}(\lambda^q\phi + \tilde{\lambda}^q\tilde{\phi})Q_R^3\right) + \\ - \left(\bar{L}_L^{1,2,3}\lambda_L^\nu H_L \nu_R^{1,2} + \bar{L}_L^{1,2,3}\lambda_L^e \tilde{H}_L E_R^{1,2} + \bar{L}_L^{1,2,3}(\lambda^l\phi + \tilde{\lambda}^l\tilde{\phi})L_R^3\right) + \text{h.c.}\,,$$

in basis with diagonal neutrino mass matrix

$$\mathcal{L}_Y = -\frac{1}{\sqrt{2}}\bar{e}_L[\lambda_L^e(v_L + h_L) + \tilde{\lambda}^l(v_1 + h_1) + \lambda^l(v_2 + h_2)]e_R + \text{h.c.}\,.$$

From this we can read the charged lepton mass matrix,

$$M^e = \frac{1}{\sqrt{2}}(\lambda_L^e v_L + \tilde{\lambda}^l v_1 + \lambda^l v_2),$$

$$\lambda_L^e = \begin{pmatrix} f_{11}^l & f_{12}^l & 0 \\ f_{21}^l & f_{22}^l & 0 \\ f_{31}^l & f_{32}^l & 0 \end{pmatrix}\ , \quad \tilde{\lambda}^l = \begin{pmatrix} 0 & 0 & \tilde{g}_{13}^l \\ 0 & 0 & \tilde{g}_{23}^l \\ 0 & 0 & \tilde{g}_{33}^l \end{pmatrix}\ . \quad \lambda^l = \begin{pmatrix} 0 & 0 & g_{13}^l \\ 0 & 0 & g_{23}^l \\ 0 & 0 & g_{33}^l \end{pmatrix}\ .$$

similar structure to previous model but 2 column matrices

scalar mixing

- without mixing with pseudo scalars in the potential

$$\begin{pmatrix} h_L \\ h_1 \\ h_2 \end{pmatrix} = \begin{pmatrix} v_L/v & 0 & v'/v \\ v_1/v & v_2/v' & -v_L v_1/v'v \\ v_2/v & -v_1/v' & -v_L v_2/v'v \end{pmatrix} \begin{pmatrix} \tilde{h} \\ H_1 \\ H_2 \end{pmatrix} .$$

- diagonalizing the charged lepton mass matrix

$$\mathcal{L}_{\mathrm{Y_e}} = -\bar{e}_L \left(\hat{M}^e (1 + \frac{\tilde{h}}{v}) + \lambda_1^e H_1 + \lambda_2^e H_2 \right) e_R + \mathrm{h.c.}$$

- with

$$\lambda_1^e = \frac{S_e^\dagger (\tilde{\lambda}^l v_2 - \lambda^l v_1) T_e}{\sqrt{2} v'}, \quad \lambda_2^e = \frac{S_e^\dagger (\lambda_L^e v' - \tilde{\lambda}^l \frac{v_1 v_L}{v'} - \lambda^l \frac{v_2 v_L}{v'}) T_e}{\sqrt{2} v}.$$

- enough to get CP violation

recall the precision tests

all looks great for the SM, implying any NP must appear above ∿ 10 TeV

almost!

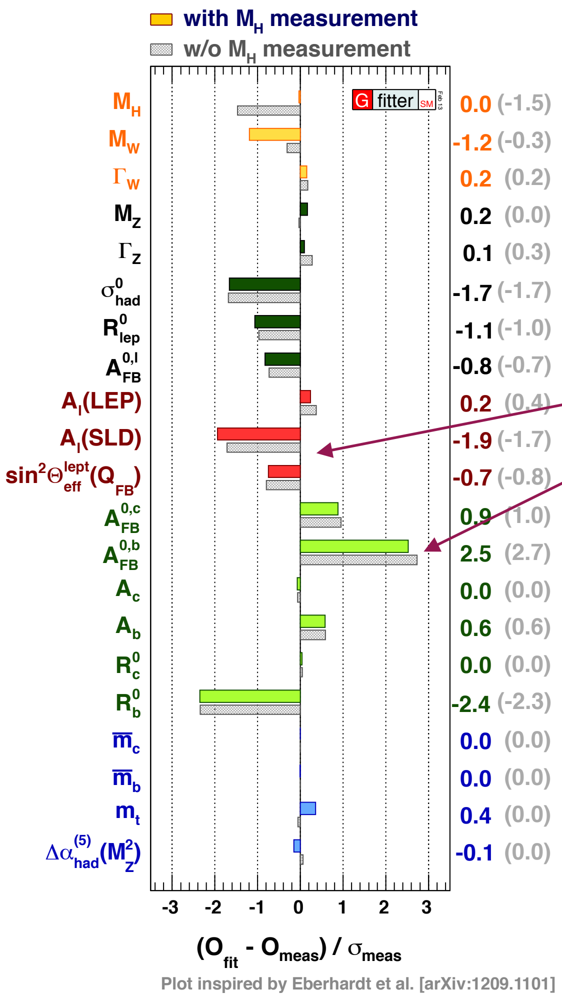
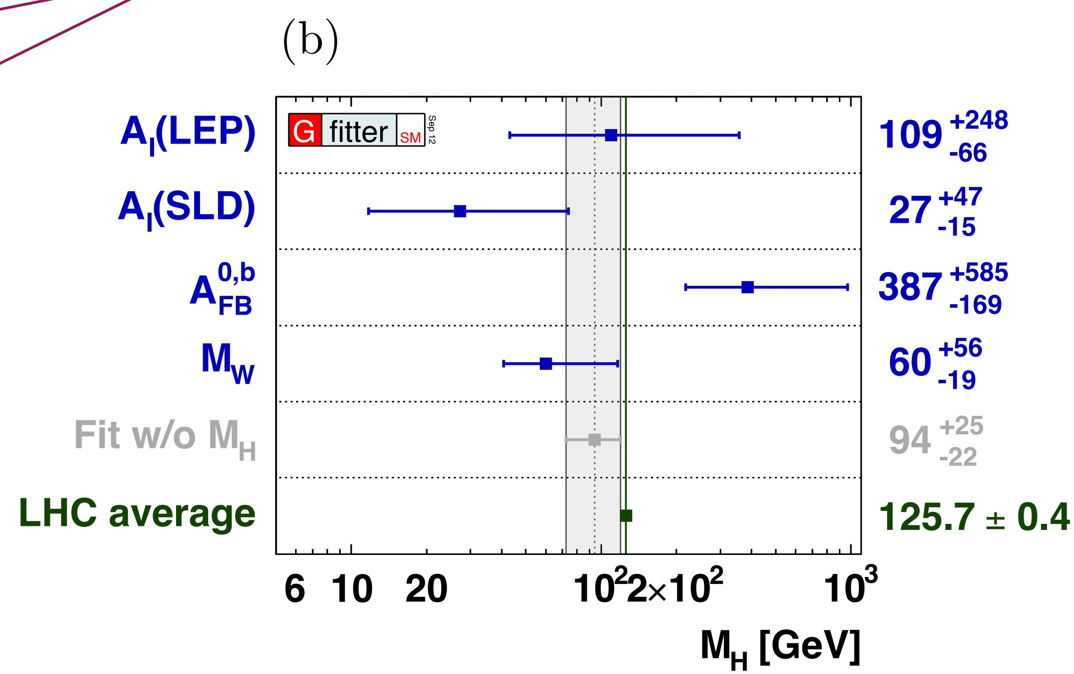
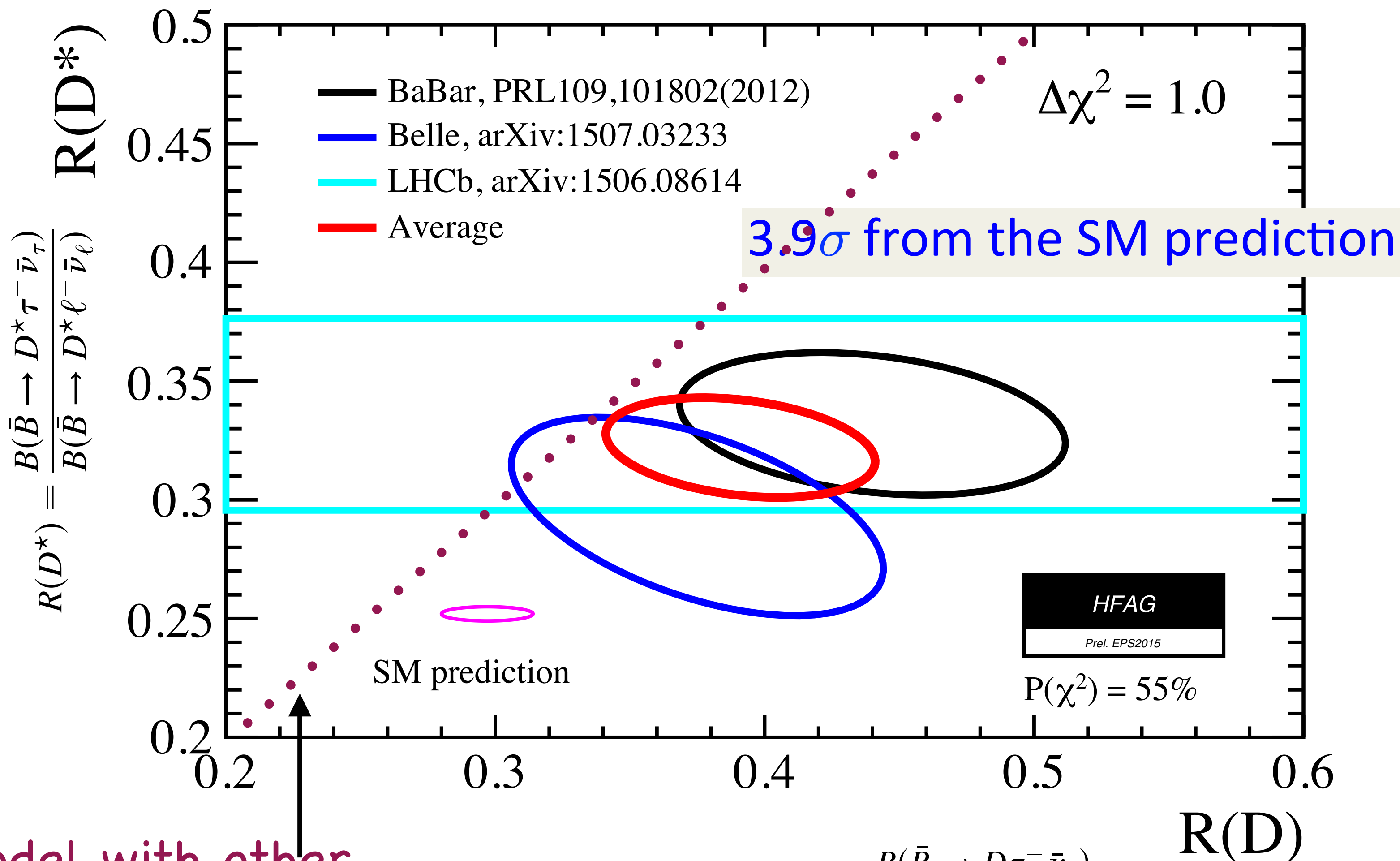


Figure 1: Differences between the SM prediction and the measured parameter, in units of the uncertainty for the fit including M_H (color) and without M_H (grey).



Baak, Kogler http://arxiv.org/pdf/1306.0571v2.pdf

Lepton universality ?

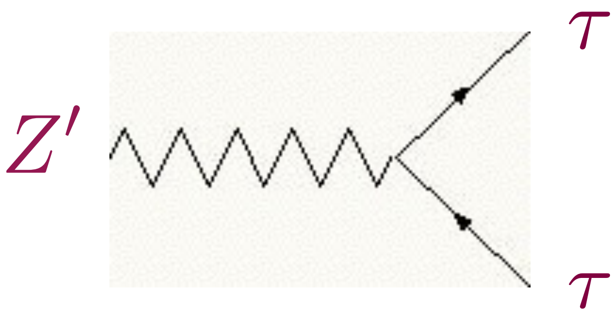


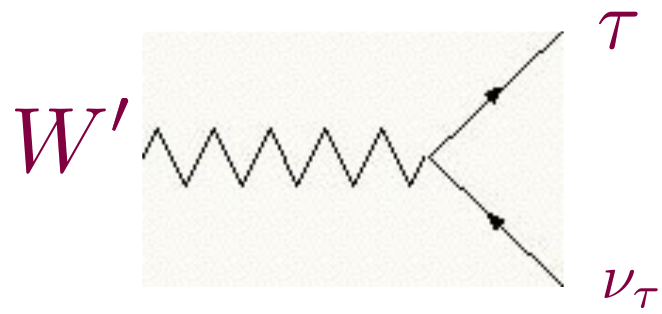
our model with other constraints $b \to s\gamma$

$$R(D) = \frac{B(\bar{B} \to D\tau^- \bar{\nu}_\tau)}{B(\bar{B} \to D\ell^- \bar{\nu}_\ell)}$$

can this model do this? - yes

- New $SU_R(2)$ for third generation (X.G. He and G.V)





- can be made to satisfy all other constraints
- predicts
  - R(D) and R(D*) approximately same enhancement
  - $M_{W'} < 1$ TeV (not ruled out in Run I, not looked at yet in Run II)
  - additional modes also enhanced $\begin{cases} b \to c\tau\nu \\ B_c^- \to \tau^-\nu \end{cases}$

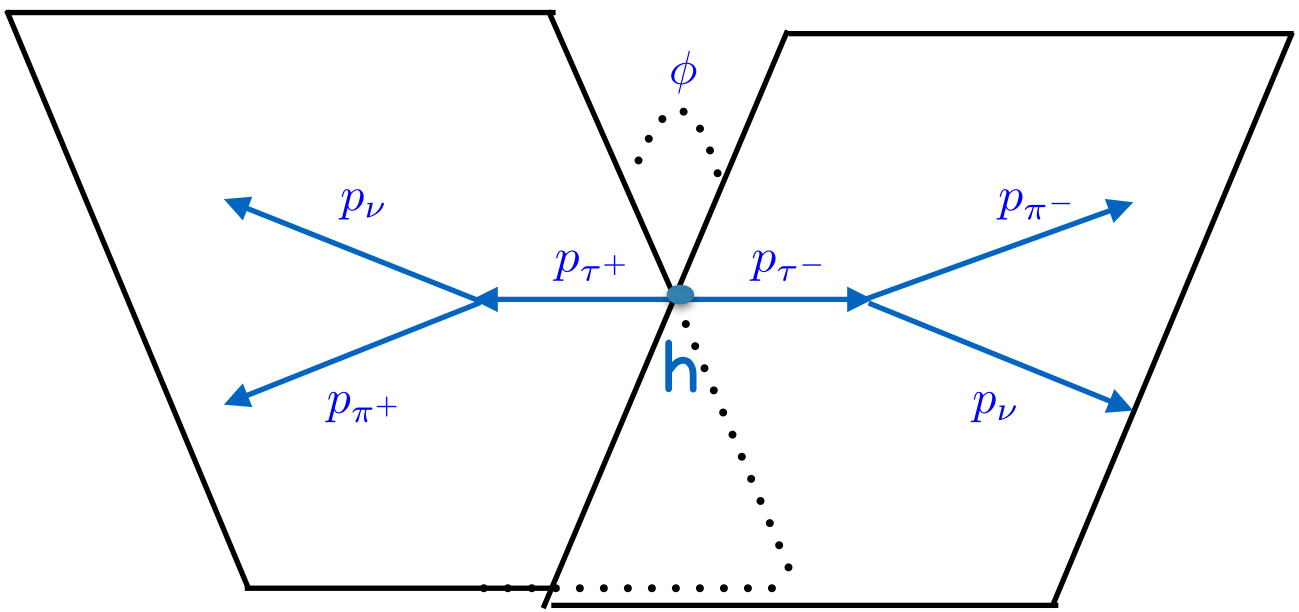
cp violation

- is the Higgs a scalar or a pseudo-scalar?
- if it doesn't have definite parity it violates CP
- this can be tested with:
  - fermion pair decay
  - spin analysed
    - top-quark, only with a heavy H
    - tau-lepton

CP violation in h $\rightarrow \tau\tau$

$$e^+e^- \to Zh \to \mu^+\mu^- h$$

higgs rest frame



$$\mathcal{O}_\pi = \vec{p}_\tau \cdot (\vec{p}_{\pi^+} \times \vec{p}_{\pi^-})$$

$$A_\pi = \frac{N(\mathcal{O}_\pi > 0) - N(\mathcal{O}_\pi < 0)}{N(\mathcal{O}_\pi > 0) + N(\mathcal{O}_\pi < 0)} = \frac{\pi}{4}\beta_\tau \frac{(r_\tau \tilde{r}_\tau)}{\beta_\tau^2 r_\tau^2 + \tilde{r}_\tau^2} \lesssim \begin{matrix} 0.11 \\ 0.4 \end{matrix}$$

democratic

hierarchical

Other correlations

$$\mathcal{O}_i = \vec{p}_{\tau^-} \cdot (\vec{p}_\ell \times \vec{p}_j)$$

$$A_i = c_i \frac{r_\tau \, \tilde{r}_\tau}{|r_\tau|^2 + |\tilde{r}_\tau|^2}$$

	Mode	Jets	c_i
1	$(\tau^- \to \nu_\tau \mu^- \bar{\nu}_\mu), (\tau^+ \to \bar{\nu}_\tau \pi^+)$	$j = \pi^+$	-0.27
2	$(\tau^- \to \nu_\tau \mu^- \bar{\nu}_\mu), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^0)$	$j = \pi^+ + \pi^0$	-0.11
3	$(\tau^- \to \nu_\tau \mu^- \bar{\nu}_\mu), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^0 \pi^0)$	$j = \pi^+ + \pi^0 + \pi^0$	-0.017
4	$(\tau^- \to \nu_\tau \mu^- \bar{\nu}_\mu), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^+ \pi^-)$	$j = \pi^+ + \pi^+ + \pi^-$	0.0005

TABLE I: Semi-leptonic modes with tau-jet producing the largest asymmetry and their respective coefficients c_i for Eq.(58)

direction of τ from secondary vertex

$$\mathcal{O}_i = \vec{p}_{\tau^-} \cdot (\vec{p}_{j1} \times \vec{p}_{j2})$$

	Mode	Jets	c_i
1	$(\tau^- \to \nu_\tau \pi^-)(\tau^+ \to \bar{\nu}_\tau \pi^+)$	$j_1 = \pi^-$, $j_2 = \pi^+$	0.79
2	$(\tau^- \to \nu_\tau \pi^-), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^0)$	$j_1 = \pi^-$, $j_2 = \pi^+ + \pi^0$	0.33
3	$(\tau^- \to \nu_\tau \pi^- \pi^0), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^0)$	$j_1 = \pi^- + \pi^0$, $j_2 = \pi^+ + \pi^0$	0.13
4	$(\tau^- \to \nu_\tau \pi^-), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^0 \pi^0)$	$j_1 = \pi^-$, $j_2 = \pi^+ + \pi^0 + \pi^0$	0.06
5	$(\tau^- \to \nu_\tau \pi^-), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^+ \pi^-)$	$j_1 = \pi^-$, $j_2 = \pi^+ + \pi^+ + \pi^-$	0.06
6	$(\tau^- \to \nu_\tau \pi^- \pi^0), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^0 \pi^0)$	$j_1 = \pi^- + \pi^0$, $j_2 = \pi^+ + \pi^0 + \pi^0$	0.02
7	$(\tau^- \to \nu_\tau \pi^- \pi^0), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^+ \pi^-)$	$j_1 = \pi^- + \pi^0$, $j_2 = \pi^+ + \pi^+ + \pi^-$	0.02
8	$(\tau^- \to \nu_\tau \pi^- \pi^0 \pi^0), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^0 \pi^0)$	$j_1 = \pi^- + \pi^0 + \pi^0$, $j_2 = \pi^+ + \pi^0 + \pi^0$	0.004
9	$(\tau^- \to \nu_\tau \pi^- \pi^0 \pi^0), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^+ \pi^-)$	$j_1 = \pi^- + \pi^0 + \pi^0$, $j_2 = \pi^+ + \pi^+ + \pi^-$	0.003
10	$(\tau^- \to \nu_\tau \pi^- \pi^+ \pi^-), (\tau^+ \to \bar{\nu}_\tau \pi^+ \pi^+ \pi^-)$	$j_1 = \pi^- + \pi^+ + \pi^-$, $j_2 = \pi^+ + \pi^+ + \pi^-$	0.003

TABLE II: Double hadronic tau decays with tau-jets producing the largest asymmetry and their respective coefficients c_i for Eq.(58).

Summary - Conclusion

- LFV is very common BSM and LFV decays of the Higgs are correlated with CP violation Higgs to di-leptons
- We have constructed two multi-Higgs models in which the Higgs has LFV decays but only one of them exhibits CP violation as well.
- These illustrate some nontrivial details of mass matrix textures necessary to predict correlations between results from flavor physics.
  - dominant hierarchical structure that produces the charged lepton masses, but the deviations are democratic. The tightest constraint arises from bounds on $h \to \mu\mu$ consistent with LFV from CMS, CP violating asymmetry < 11%.
  - corrections to the SM lepton mass matrices are also hierarchical as in the Cheng-Sher ansatz. Tightest constraints on new physics arise from $h \to \tau\tau$, consistent with LFV from CMS, CP violating asymmetry < 40%.