Flavon-Induced Lepton Flavour Violation

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In collaboration with
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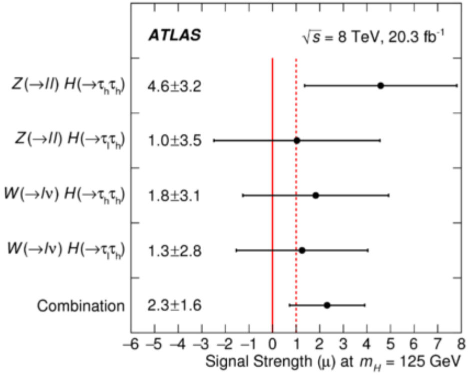
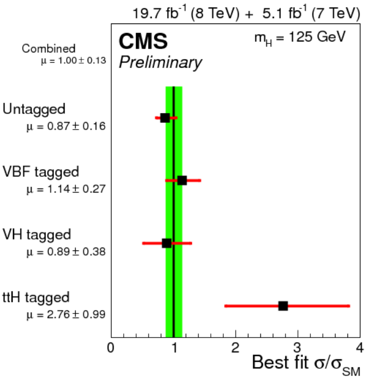
work in progress

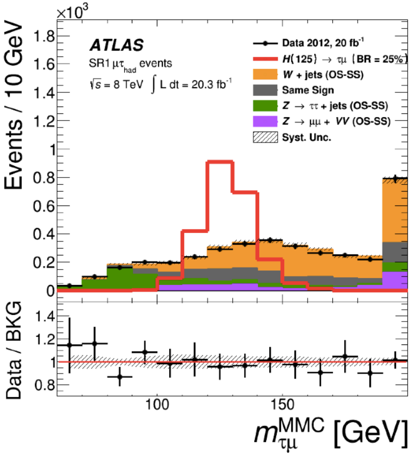
Scalars 2015, Warsaw

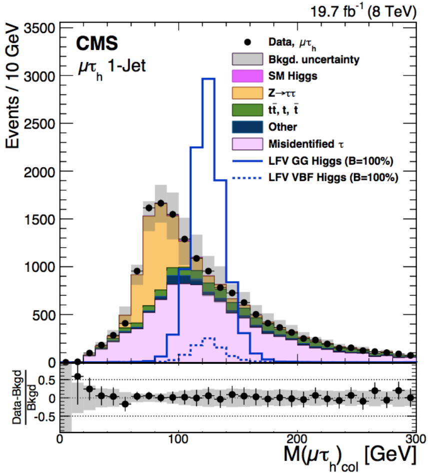
The Higgs has been discovered



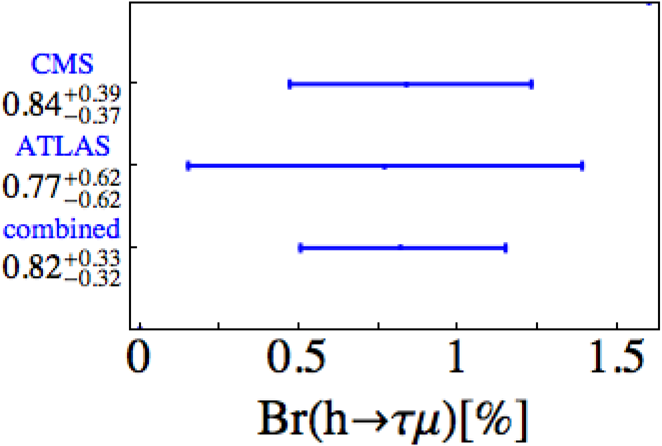


The discovered Higgs deviates from SM





Naive combined result BR($h \to \mu\tau$)



Charged Lepton Flavour Violation in SM

The lepton Yukawa part of the SM Lagrangian:

$$\begin{aligned}\mathcal{L}_{SM} \quad &\supset \quad \frac{v_h}{\sqrt{2}}\; Y_{ij}\; \bar{l}'_{L,i} l'_{R,j}(1+\frac{h}{v_h}) \\ &\equiv v_h \bar{l}_L Y_{\rm diag} l_R + \bar{l}_L \frac{Y_{\rm diag}}{\sqrt{2}} l_R h\end{aligned}$$

CLFV processes are absent in SM.

To produce CLFV $\rightarrow$ go Beyond SM

The Froggat-Nielsen mechanism

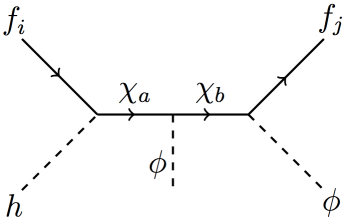
Froggat-Nielsen mechanism - global $U(1)$ symmetry

A Higgs doublet and a flavon singlet:

$$H = \begin{pmatrix} 0 \\ \frac{v_h + h}{\sqrt{2}} \end{pmatrix}, \qquad \Phi = \left(\frac{v_\phi + \phi}{\sqrt{2}} \right)$$

$U(1)$-invariant Yukawa-like couplings:

$$c_{ia} \; f_i \chi_a \frac{h}{\sqrt{2}}, \qquad b_{ia} \; f_i \chi_a \frac{\phi}{\sqrt{2}}$$



Froggat-Nielsen mechanism

The effective operators after integrating out the heavy fermions:

$$c_{ij}^f \; \bar{f}_{L,i} f_{R,j} \frac{h}{\sqrt{2}} \left(\frac{\phi}{\sqrt{2}\Lambda} \right)^x , \qquad q_{\bar{L},i} + q_{R,j} + q_h + q_\phi x = 0$$

Particle	$\bar{f}_{L,i}$	$f_{R,i}$	h	ϕ
$U(1)$ charge	$q_{\bar{L},i}$	$q_{R,i}$	q_h	q_ϕ

After SSB:

$$\mathcal{L}_{Yukawa} \supset c_{ij}^f \left(\frac{v_\phi}{\sqrt{2}\Lambda} \right)^{-\frac{1}{q_\phi}(q_{\bar{L},i}+q_{R,j}+q_h)} \bar{f}_{L,i} f_{R,j} \frac{h}{\sqrt{2}}$$

The SM Yukawa coupling $(q_\phi = -1, q_h = 0)$

$$Y_{ij}^f = c_{ij}^f \; \epsilon^{\overbrace{(q_{\bar{L},i} + q_{R,j})}^{n_{ij}}} \quad \text{with} \quad \epsilon = \frac{v_\phi}{\sqrt{2}\Lambda}$$

Froggat-Nielsen mechanism

Leptonic part of the Lagrangian

$$\mathcal{L}_{eff.} \supset \frac{v_h}{\sqrt{2}} Y_{ij} \bar{l}'_{L,i} l'_{R,j} (1 + \frac{h}{v_h}) + n_{ij} v_h Y_{ij} \frac{\phi}{v_\phi} \bar{l}'_{L,i} l'_{R,j}$$

$$Y_{\rm diag} = U_L \; Y_{ij} \; U_R^\dagger$$

$$\mathcal{L}_{eff.} \supset \bar{l}_L M_{\rm diag} l_R + \bar{l}_L \frac{Y_{\rm diag}}{\sqrt{2}} l_R h + \frac{\kappa_{ij}}{v_\phi} \bar{l}_{L,i} l_{R,j} \phi + h.c.$$

CLFV processes with coupling

$$\tilde{\kappa}_{ij} = \frac{\kappa_{ij}}{v_\phi} = \frac{1}{v_\phi} \left[m_j \sum_{k=1}^{3} q_{\bar{L},k} (U_L)_{ik} (U_L)^*_{jk} + m_i \sum_{k=1}^{3} q_{R,k} (U_R)_{ik} (U_R)^*_{jk} \right]$$

Higgs-flavon mixing

The scalar potential

$$V(H,\Phi) = -\mu_h^2(H^\dagger H)+\lambda_h(H^\dagger H)^2-\mu_\phi^2(\Phi^\dagger\Phi)+\lambda_\phi(\Phi^\dagger\Phi)^2+\lambda_{h\phi}(H^\dagger H)(\Phi^\dagger\Phi)$$

with

$$H = \begin{pmatrix} 0 \\ \frac{v_h+h}{\sqrt{2}} \end{pmatrix}, \qquad \Phi = \left(\frac{v_\phi+\phi}{\sqrt{2}}\right)$$

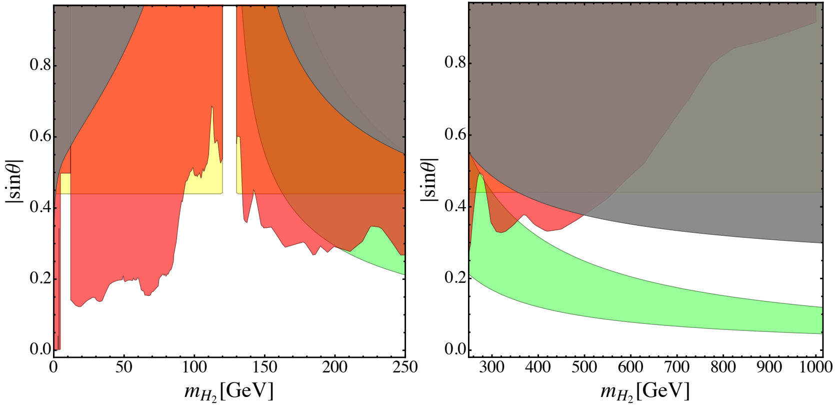
The physical states

$$\begin{pmatrix} H_1 \\ H_2 \end{pmatrix} \equiv \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} h \\ \phi \end{pmatrix}$$

where

$$\tan 2\theta = \frac{\lambda_{h\phi} v_h v_\phi}{\lambda_h v_h^2 - \lambda_\phi v_\phi^2}$$

How much Higgs-flavon mixing is allowed?



Excluded at 95 % CL by direct searches (red), precision tests (gray), and H_1 couplings measurements (yellow). [Falkowski,Gross,Lebedev '15]

Bounds from CLFV processes

Observable	Present limit	Experiment
$\mathrm{BR}(\mu \to eee)$	1.0×10^{-12}	SINDRUM
$\mathrm{BR}(\tau \to eee)$	3.0×10^{-8}	HFAG
$\mathrm{BR}(\tau \to \mu\mu\mu)$	2.0×10^{-8}	HFAG
$\mathrm{BR}(\mu \to e\gamma)$	5.7×10^{-13}	MEG
$\mathrm{BR}(\tau \to \mu\gamma)$	4.4×10^{-8}	HFAG
$\mathrm{BR}(\tau \to e\gamma)$	3.3×10^{-8}	HFAG
$\mathrm{BR}(\mu\text{-}e, Au)$	7.0×10^{-13}	Bertl *et. al.*

Gauged $U(1)$ Froggat-Nielsen symmetry

Gauged $U(1)$ Froggat-Nielsen symmetry

$G_{SM} \times U'(1)$ symmetry $\to$ new gauge field with new gauge coupling

$$\mathcal{L} \supset D'_\mu \Phi^* \ D'^\mu \Phi + g_4 B'_\mu \sum_i q_i \ \overline{\psi}_{\mathrm{SM}_i} \gamma^\mu \ \psi_{\mathrm{SM}_i} + \overline{\chi}(i\partial_\mu + g_4 q' B'_\mu)\gamma^\mu \chi$$

with

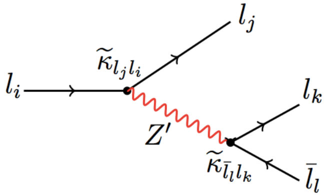
$$D'_\mu = \partial_\mu - i g_4 q' B'_\mu$$

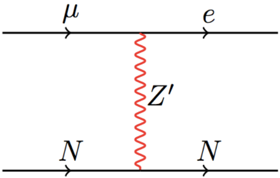
The new massive gauge boson

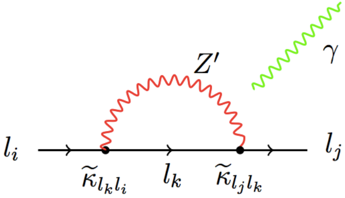
$$m_{Z'} = |g_4 q_\phi v_\phi| = g_4 v_\phi$$

with $q_\phi = -1$.

CLFV processes mediated by Z'







Gauged $U(1)$ FN symmetry

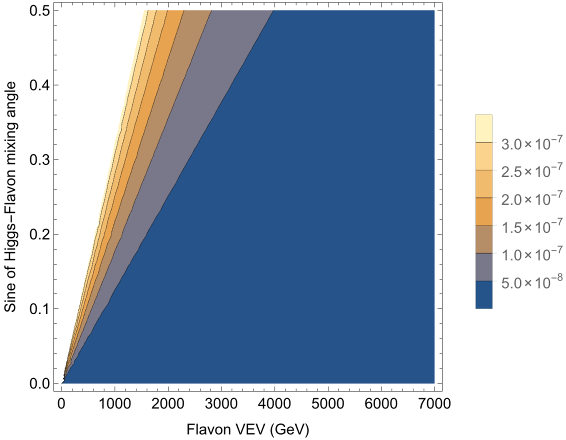
A texture for $\epsilon = 0.01$ satisfying all CLFV bounds

Particle	e_L	e_R	μ_L	μ_R	τ_L	τ_R	H	ϕ
$U'(1)$ charge	2	1	1	1	0	1	0	-1

$$Y = \begin{pmatrix} \epsilon^3 & \epsilon^3 & \epsilon^3 \\ \epsilon^2 & \epsilon^2 & \epsilon^2 \\ \epsilon & \epsilon & \epsilon \end{pmatrix}, \quad \tilde{\kappa} = \frac{1}{v_\phi} \begin{pmatrix} 10^{-3} & 4\times 10^{-5} & 8\times 10^{-4} \\ 2\times 10^{-7} & 0.2 & -0.07 \\ 2.4\times 10^{-7} & -4\times 10^{-3} & 1.8 \end{pmatrix}$$

The strongest bound: the $\mu \to eee$ process leads to $v_\phi > 7$ TeV

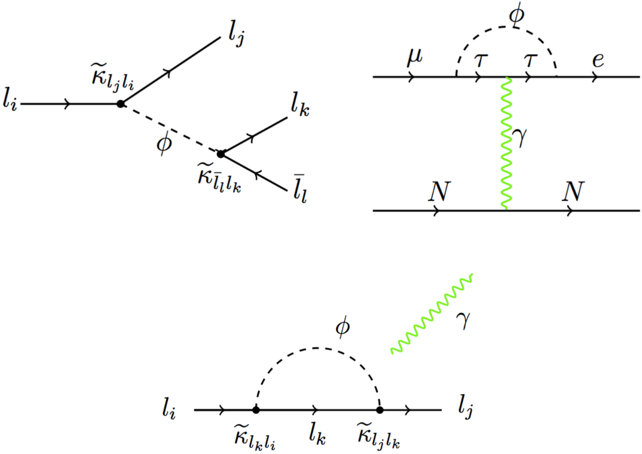
The BR($h \to \mu\tau$) for $v_\phi > 7$ TeV



Discrete Froggat-Nielsen symmetry

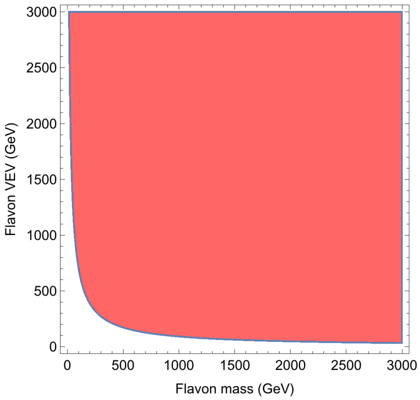
Negligible Higgs-flavon mixing ($\lambda_{h\phi} = 0$)

CLFV processes mediated by pure flavon, ϕ



Negligible Higgs-flavon mixing ($\lambda_{h\phi} = 0$)

Strongest bound: the $\mu \to e\gamma$ process



No contribution to BR($h \to \mu\tau$)

Non-negligible Higgs-flavon mixing ($\lambda_{h\phi} \neq 0$)

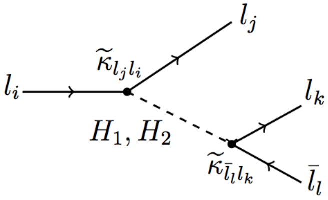
The physical states

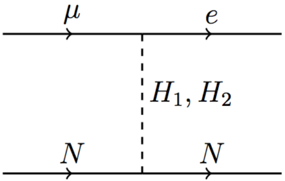
$$\begin{pmatrix} H_1 \\ H_2 \end{pmatrix} \equiv \begin{pmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{pmatrix} \begin{pmatrix} h \\ \phi \end{pmatrix}$$

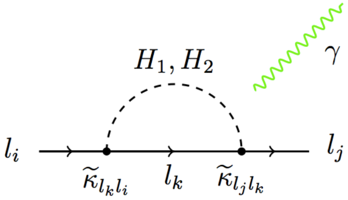
both contribute to CLFV terms

$$\begin{aligned} \mathcal{L} \quad \supset \quad & \left[\cos\theta\, \frac{y^e_{ij}}{\sqrt{2}} + \sin\theta\, \widetilde{\kappa}_{ij}\right] \bar{l}_i P_R l_j H_1 + \left[\cos\theta\, \frac{y^e_{ij}}{\sqrt{2}} + \sin\theta\, \widetilde{\kappa}^*_{ji}\right] \bar{l}_i P_L l_j H_1 \\ + \quad & \left[\cos\theta\, \widetilde{\kappa}_{ij} - \sin\theta\, \frac{y^e_{ij}}{\sqrt{2}}\right] \bar{l}_i P_R l_j H_2 + \left[\cos\theta\, \widetilde{\kappa}^*_{ji} - \sin\theta\, \frac{y^e_{ij}}{\sqrt{2}}\right] \bar{l}_i P_L l_j H_2 \end{aligned}$$

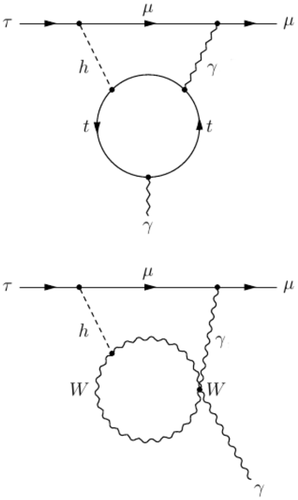
CLFV processes mediated by H_1 and H_2







CLFV processes mediated by H_1 and H_2



[Harnik, Kopp, Zupan '15]

One example

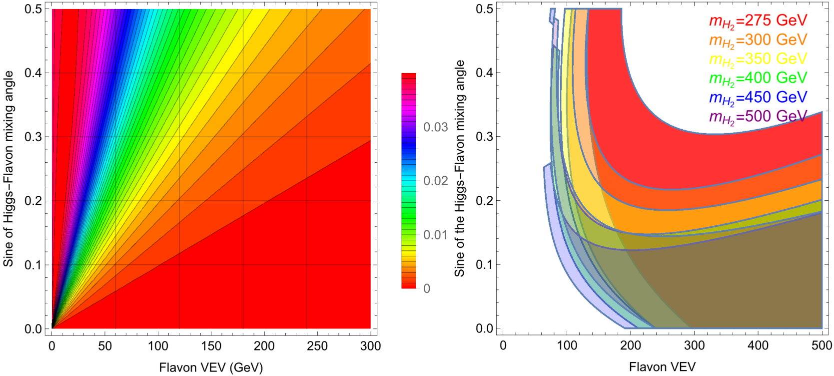
The discrete charge assignments for $\epsilon = 0.1$

Particle	e_L	e_R	μ_L	μ_R	τ_L	τ_R	H	ϕ
Charge	6	0	4	0	2	1	0	-1

The texture satisfying all CLFV bounds

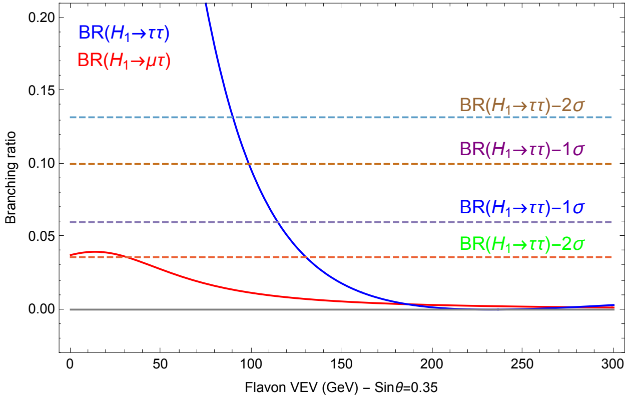
$$Y = \begin{pmatrix} \epsilon^6 & \epsilon^6 & \epsilon^7 \\ \epsilon^4 & \epsilon^4 & \epsilon^5 \\ \epsilon^2 & \epsilon^2 & \epsilon^3 \end{pmatrix}, \quad \tilde{\kappa} = \frac{1}{v_\phi} \begin{pmatrix} 0.003 & -0.0003 & -0.0008 \\ -0.004 & 0.5 & 0.1 \\ 0.08 & -0.9 & 4.5 \end{pmatrix}$$

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



For $\sin\theta = 0.35,\ v_\phi = 110\ \text{GeV},\ m_\phi = 400 GeV \to \mathrm{BR}(h \to \mu\tau) \simeq 0.01$

BR($h \to \tau\tau$)



Summary

- The combined result for $\mathrm{BR}(h \to \mu\tau) = 0.8 \pm 0.3$.
- CLFVs are absent in the SM.
- Foggat-Nielsen mechanism with a discrete symmetry is capable of producing a $\mathrm{BR}(h \to \mu\tau) \sim 0.1$ while satisfying all bounds.