Probing NP with tau LFV and EDM measurements

Oscar Vives

Workshop on τ-charm at high luminosity.

La Biodola, *27–31/05/2013*

FLAVOUR PROBLEM

1.- All flavour observables consistent with a Yukawa description of flavour in SM.

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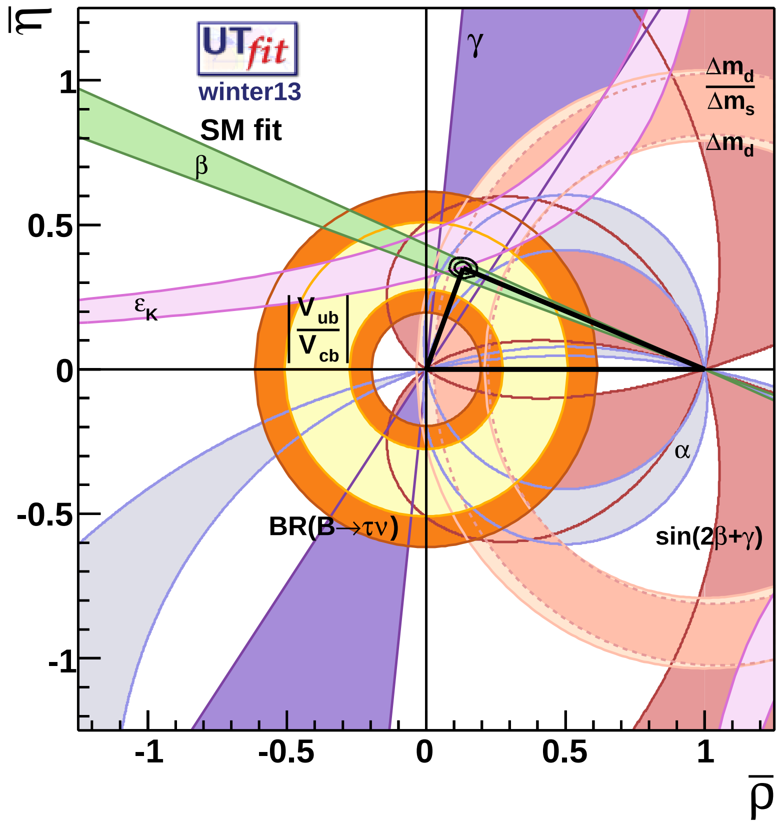

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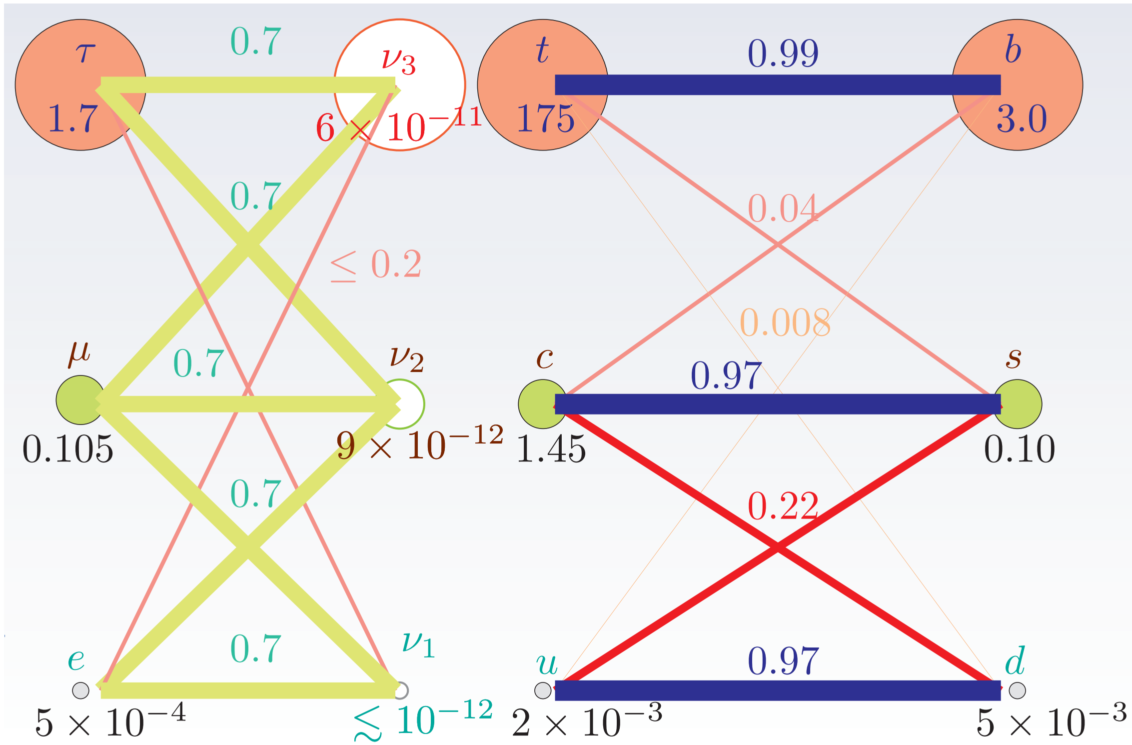

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$$\Downarrow$$

Still, lots of work needed!!

Standard Model

All Observed *Flavour Changing Neutral Currents* can be accomodated in Yukawa couplings:

$$\mathcal{L}_Y \quad = \quad H \, \bar{Q}_i \, Y^d_{ij} \, d_j \quad + \quad H^* \, \bar{Q}_i \, Y^u_{ij} \, u_j$$

Only masses and CKM mixings, $V_{\rm CKM}$, observable...

$\Longrightarrow$ a) what is the origin of the Yukawa structures??

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New Physics

New flavour structures generically present $\Longrightarrow$ measure of new observables provides new information on flavour origin...

SUSY Flavour (and CP) problems

Soft masses fixed by $m_{3/2}$. $O(m_{3/2})$ elements in soft matrices.

$\Rightarrow$ **Severe FCNC problem !!!**

CP broken, we can expect all complex paramaters have $O(1)$ phases. $\Rightarrow$ **Too large EDMs !!!**

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SM Flavour and CP

Fermion masses fixed by M_W. If $O(1)$ elements in Yukawa matrices and $O(1)$ phases

$\Longrightarrow$ **Impossible reproduce masses, mixings and CP observables !!!**

Flavoured New Physics

2 Higgs Doublet Models

- Four possible Yukawa matrices. $\Longrightarrow$ Large FCNC.
- Discrete symmetry (type I, type II) to forbid FCNC. $\Longrightarrow$ No connection with structure of flavour matrices.
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Supersymmetry

- Five sfermion mass matrices and Three trilinear matrices $\Rightarrow$ Lots of new observables to understand flavour.

Complementarity LHC-Flavour

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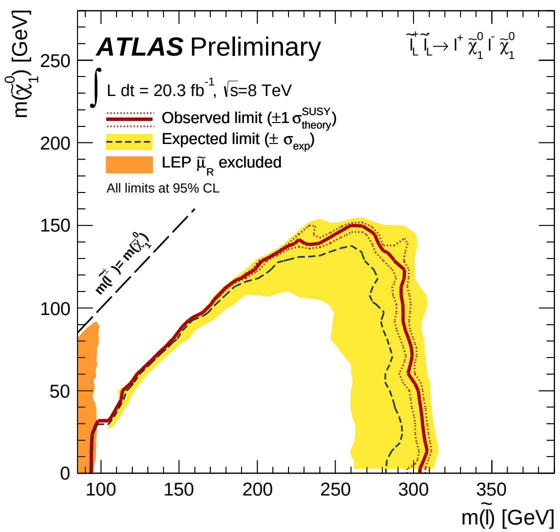
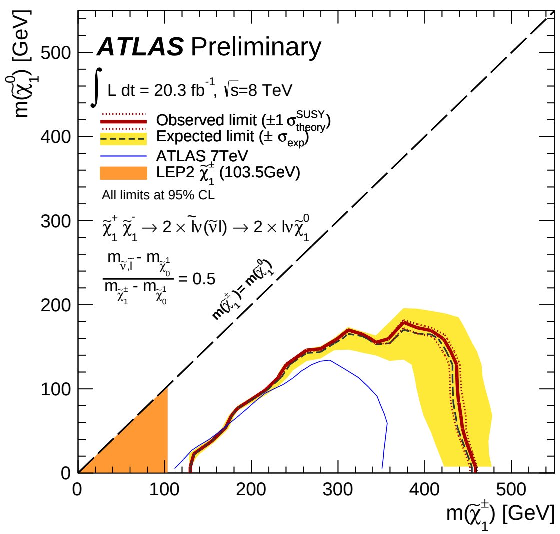
EW production: Direct limits on chargino and slepton masses

$\longrightarrow$ EW production chargino/neutralino and slepton. $M \gtrsim 300$ GeV

ATLAS-CONF-2013-049, CMS PAS SUS-12-022





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LHC–Flavour fact. Feedback:

1. LHC measures squark, gluino, neutralino mass scale
2. With this information Flavour factories determine $\tan\beta$ and mixings
3. These parameters help reanalyze LHC data
4. ...

MI Constraints

$\tan\beta$ = 10, $m_{\tilde{l}}$ = 400 GeV, M_2 =150 GeV.

δ^l_{13}	$\tau \to e\,\gamma$	$\tau \to e\,e\,e$	$\tau \to e\mu\mu$
LL	0.15	—	-
RR	-	-	-
LR/RL	0.04	0.5	-

δ^l_{23}	$\tau \to \mu\,\gamma$	$\tau \to \mu\,\mu\,\mu$	$\tau \to \mu\,e\,e$
LL	0.12	-	-
RR	-	-	-
LR/RL	0.03	-	0.5

BR($\tau \to e\,\gamma$) $< 1.2 \times 10^{-8}$, BR($\tau \to e\,\mu\,\mu$) $< 2. \times 10^{-7}$,
BR($\tau \to \mu\,\gamma$) $< 4.8 \times 10^{-8}$, BR($\tau \to \mu\,\mu\,\mu$) $< 2 \times 10^{-7}$

τ-CHARM PHYSICS

- 3rd generation (Yukawa) couplings larger, $\Rightarrow$ sizeable effects possible

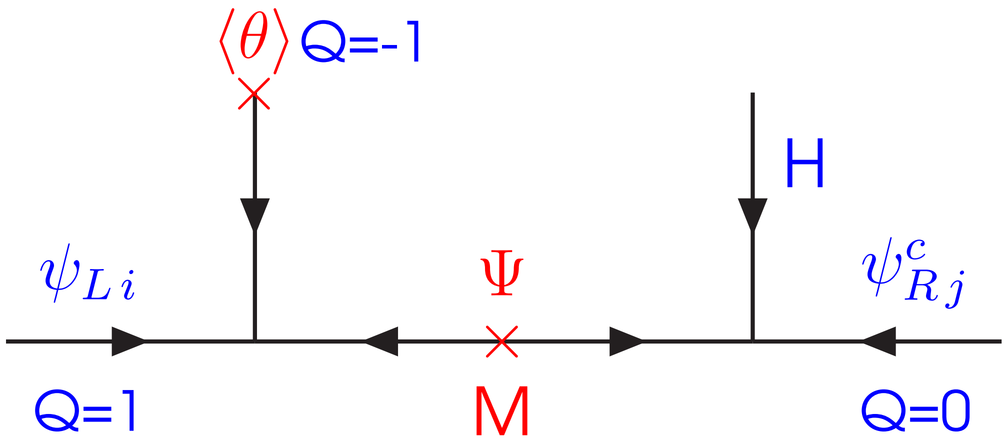
- Importance of polarization $\rightarrow$ Decay of a polarized τ. Access to different (LFV) couplings.

  $\Longrightarrow$ LFV decays: $\tau \rightarrow \mu\gamma, \tau \rightarrow lll$.

  $\Longrightarrow$ CP violation. τ Electric Dipole Moment (and also AMM)

FLAVOUR SYMMETRIES IN SUSY

- Very different elements in Yukawas: $y_t \simeq 1$, $y_u \simeq 10^{-5}$
- Expect couplings in a "fundamental" theory $\mathcal{O}(1)$
- Small couplings generated at higher order or function of small vevs.
- Froggatt-Nielsen mechanism and flavour symmetry to understand small Yukawa elements. Example: $U(1)_{fl}$



$$\Rightarrow Y_{ij} = \left(\frac{\langle\theta\rangle}{M}\right) \ll 1$$

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$\Downarrow$

We can <u>relate</u> the structure in Yukawa matrices to the nonuniversality in Soft Breaking masses !!!

Symmetric texture

- Non-Abelian flavour symmetries.

$$Y^{d,e} = \begin{pmatrix} 0 & 1.5\ \varepsilon^3 & 0.4\ \varepsilon^3 \\ 1.5\ \varepsilon^3 & \Sigma\ \varepsilon^2 & 1.3\ \Sigma\ \varepsilon^2 \\ 0.4\ \varepsilon^3 & 1.3\ \Sigma\ \varepsilon^2 & 1 \end{pmatrix} y_b$$

- Universal sfermion masses in in unbroken limit:

$$\mathcal{L}_{m^2} = m_0^2 \Phi^\dagger \Phi = m_0^2\, (\phi_1\ \phi_2\ \phi_3)^* \begin{pmatrix} \phi_1 \\ \phi_2 \\ \phi_3 \end{pmatrix}$$

- After symmetry breaking:

$$M^2_{\tilde{D}_R, \tilde{E}_L} \simeq \begin{pmatrix} 1 + \bar{\varepsilon}^3 & \bar{\varepsilon}^3 & 0 \\ \bar{\varepsilon}^3 & 1 + \bar{\varepsilon}^2 & \bar{\varepsilon}^2 \\ 0 & \bar{\varepsilon}^2 & 1 + \bar{\varepsilon} \end{pmatrix} m_0^2$$

Asymmetric texture

- Abelian flavour symmetries.

$$Y^{d,e} = \begin{pmatrix} \varepsilon^4 & \varepsilon^3 & \varepsilon^3 \\ \varepsilon^3 & \varepsilon^2 & \varepsilon^2 \\ \varepsilon & 1 & 1 \end{pmatrix} y_b$$

- In principle nonuniversal masses in unbroken symmetry:

$$\mathcal{L}_{m^2} = m_1^2\ \phi_1^* \phi_1 + m_2^2\ \phi_2^* \phi_2 + m_3^2\ \phi_3^* \phi_3$$

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Lepton Flavour violation

Off-diagonal entries in slepton masses generate *LFV* processes:

$$\mathrm{BR}(l_i \to l_j \gamma) \simeq \frac{3\pi\alpha_2^3}{G_F^2} \left| \frac{(\delta_{\mathrm{L}}^e)_{ij}}{m_{\tilde{l}}^2} \frac{\mu M_2 \tan\beta}{(M_2^2 - \mu^2)} F_{2L}(a_2, b) \right|^2$$

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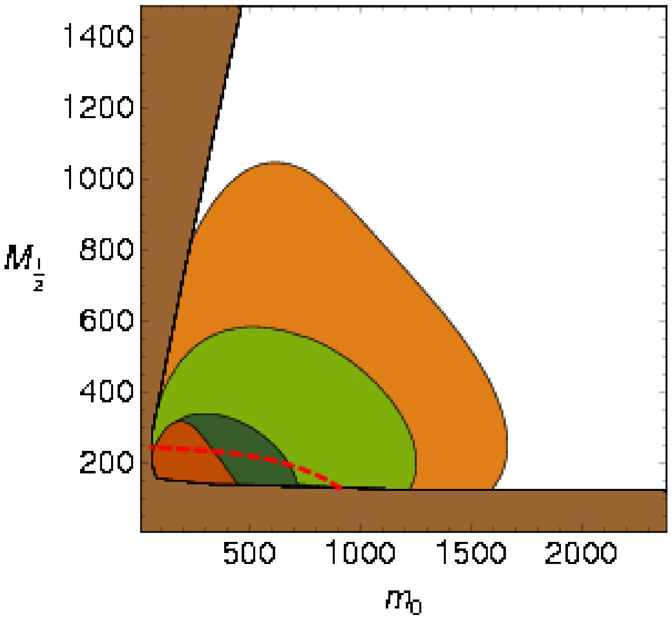
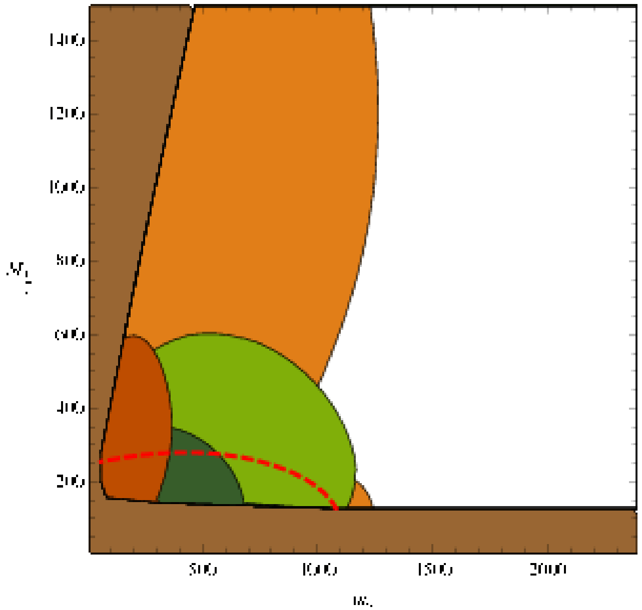
$\tan\beta = 10,\, A_0 = 0$ $\qquad$ $\tan\beta = 10,\, A_0 = m_0$





Brown(light):Present (fut.) $\mu \to e\gamma$, Green (light): Present (fut.) $\tau \to \mu\gamma$.

Flavoured EDMs

– SUSY EDMs in presence of flavour-blind phases (φ_μ, φ_A) directly proportional to lepton masses,

$$d^l_{\chi^+} \simeq \frac{-\alpha\, e\, m_l \tan\beta}{4\pi \sin^2\theta_W} \frac{\mathrm{Im}[M_2\, \mu]}{m^2_{\tilde{\nu}_e}} \frac{A(r_1) - A(r_2)}{m^2_{\chi^+_1} - m^2_{\chi^+_2}}$$

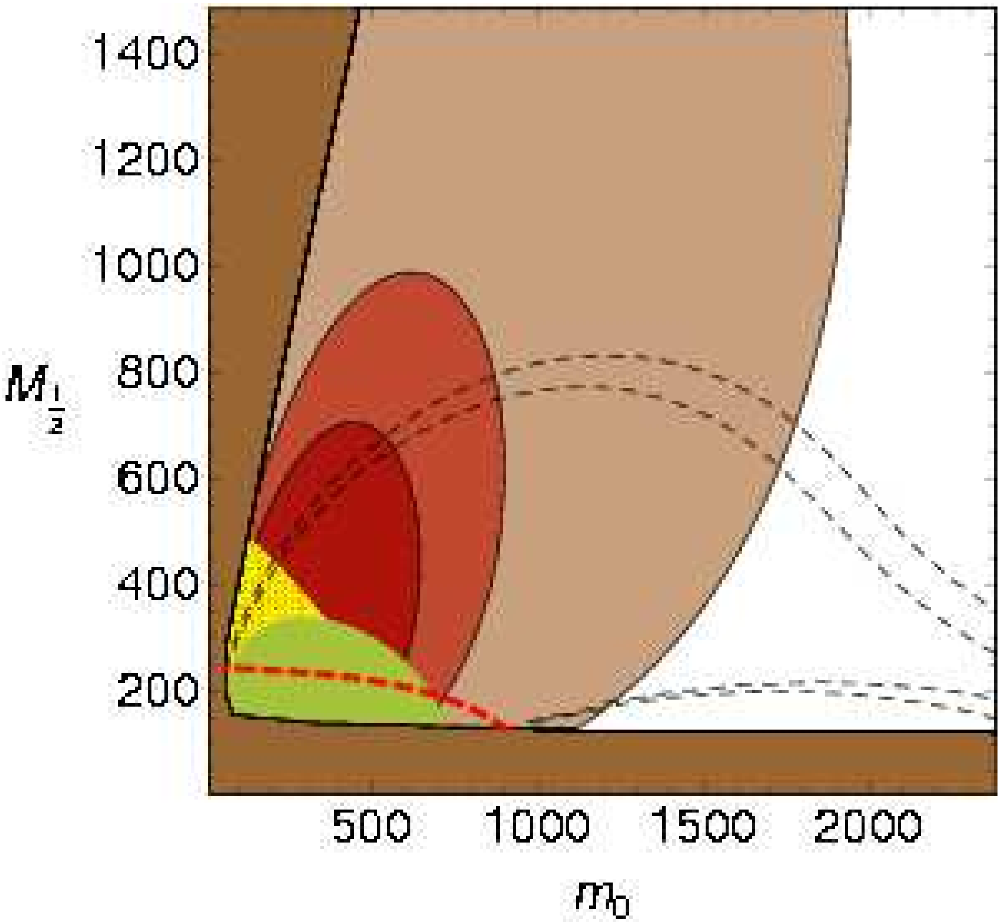
– Still, if $\varphi_\mu, \varphi_A = 0$, contributions to EDMs from offdiagonal elements in sfermion masses:

$$d_e \propto (\delta^e_{LL})_{1i}(\delta^e_{LR})_{i1}\, f_1 + (\delta^e_{LR})_{1i}(\delta^e_{RR})_{i1}\, f_2 + (\delta^e_{LL})_{1i}(\delta^e_{LR})_{ij}(\delta^e_{RR})_{j1} f_3$$

– In 2HdM d_l proportional to three masses and mixings

$$d_l \propto m_l\, m_i^2\, |K_{li}|^2\, f$$

$\Rightarrow$ Three leptonic EDMs must be measured independently to discriminate the source!!!



From light to dark: $d_e = 1 \times 10^{-30}, 5 \times 10^{-29}, 1 \times 10^{-29}$ e cm

DECAY OF POLARIZED τ

– τ polarized, $P_{z,x}$, in the presence of initial beam polarization, P_e:

$$P_{z'}^{(-)}(\theta, P_e) = -\frac{8G_F\, s}{4\sqrt{2}\pi\alpha}\,\mathrm{Re}\{\frac{g_V^l - Q_b g_V^c \Upsilon(s)}{1+Q_c^2\Upsilon(s)}\} \times \left(g_A^\tau \frac{|\vec{p}|}{p^0} + 2\, g_A^e \frac{\cos\theta}{1+\cos^2\theta}\right) + P_e \frac{\cos\theta}{1+\cos^2\theta}\,.$$

– Large τ polarization can be used to measure (or constrain) different MI through angular distrib.

$$A_L^{ij} = \frac{\alpha_2}{4\pi}\frac{\delta_{\mathrm{LL}}^{ij}}{m_{\tilde{l}}^2}\left(A(x_a) + B(x_a)\tan\beta\right) + \frac{\alpha_1}{4\pi}\,\frac{\delta_{\mathrm{RL}}^{ij}}{m_{\tilde{l}}^2}\,\left(\frac{M_1}{m_{l_i}}\right)\, C(x_a)\,,$$

$$A_R^{ij} = \frac{\alpha_1}{4\pi}\left[\frac{\delta_{\mathrm{RR}}^{ij}}{m_{\tilde{l}}^2}\left(A'(x_a) + \tan\beta B'(x_a)\right) + \frac{\delta_{\mathrm{LR}}^{ij}}{m_{\tilde{l}}^2}\,\left(\frac{M_1}{m_{l_i}}\right) C'(x_a)\right],$$

Conclusions

τ-Charm factory necessary
to solve the flavour problem.

$\Downarrow$

- New colorLR flavour structures provide valuable information on origin of flavour
- LFV processes, $\tau \to \mu\gamma$, $\tau \to lll$, constrain 3rd generation couplings.
- Ratios of leptonic EDMs depend on flavour structures and new physics model.
- Beam polarization: new tool to be explored.
- LFV and EDMs can explore large areas of flavour MSSM.