Flavor in SUSY after LHC

Oscar Vives

International Conference on Neutrinos and Dark Matter
Hurghada, 11-14/01/2020

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Flavour in Standard Model

All Observed *Flavour transitions* can be accomodated in Yukawa couplings:

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

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

But... $\Rightarrow$ a) what is the origin of the Yukawa structures??
b) why is there a CP-violating phase in CKM??

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New Physics

New flavour structures generically present $\Rightarrow$ 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

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

Flavour symmetries in SUSY

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

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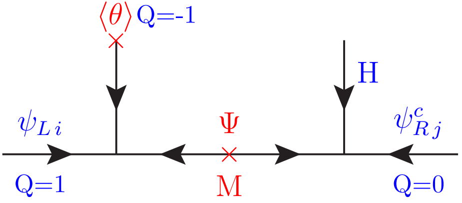

$$\Rightarrow \; Y_{ij} = \left(\frac{\langle\theta\rangle}{M}\right) \ll 1$$

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- Yukawa couplings forbidden by symmetry, generated only after Spontaneous Symmetry Breaking.

- Unbroken symmetry applies both to fermion and sfermions.
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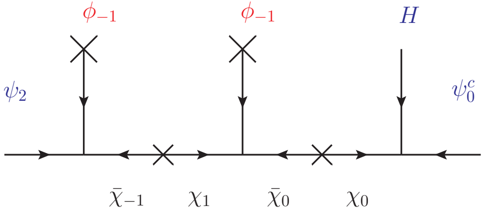
New information on flavor if Yukawa matrices and soft terms **not simultaneously diagonalizable.**

Froggatt-Nielsen effective theory

- Yukawa couplings in W_{eff} after integration of heavy states.



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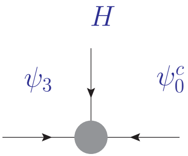

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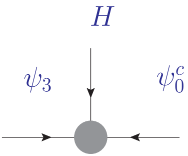
$\Rightarrow$ $Y_{ij} \sim$ 

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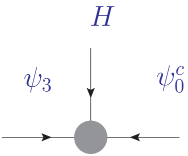
$\Rightarrow$ $Y_{ij} \sim$ 

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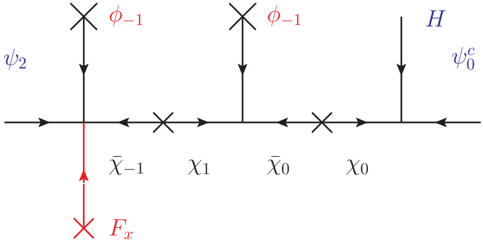

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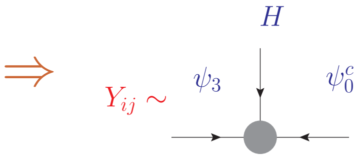

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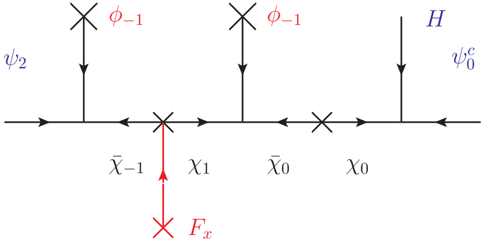

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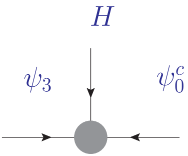

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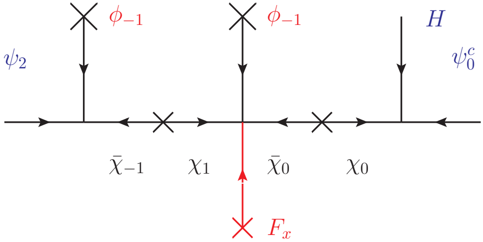

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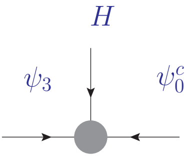

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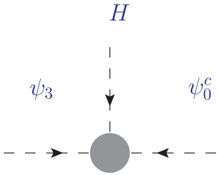
$Y_{ij}^A \sim$



$= 5\ m_0\ Y_{ij}$

Mediator Superpotential

$$W \supset g \sum_{q_i} \left(\psi_{q_i}\bar{\chi}_{-q_i+1}\phi \;+\; \chi_{q_i}\bar{\chi}_{-q_i+1}\phi \;+\; \chi_{q_i-1}\bar{\chi}_{-q_i}\bar{\phi} \;+\; \bar{\chi}_{-q_i}\psi^c_{r,q_i}H\right)$$
$$\;+\; M\sum_{q_i}\chi_{q_i}\bar{\chi}_{-q_i} \;+\; M\phi\bar{\phi} \;+\; \ldots$$

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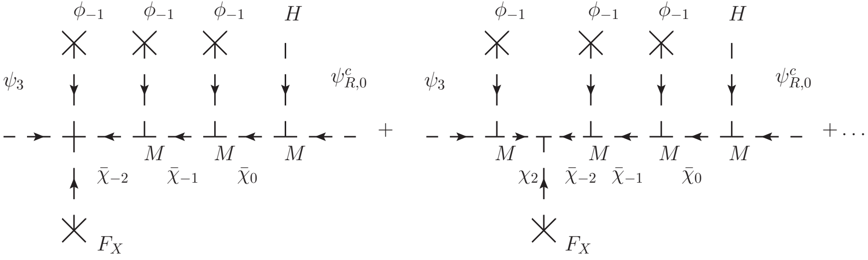
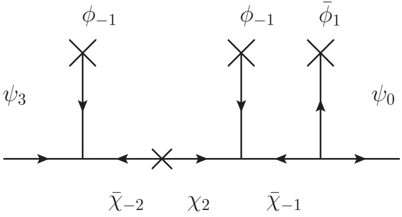
Diagrams in components



- Similar with corrections to kinetic terms and soft masses.



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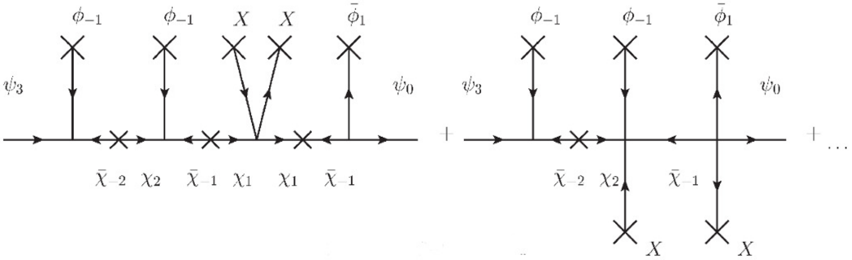

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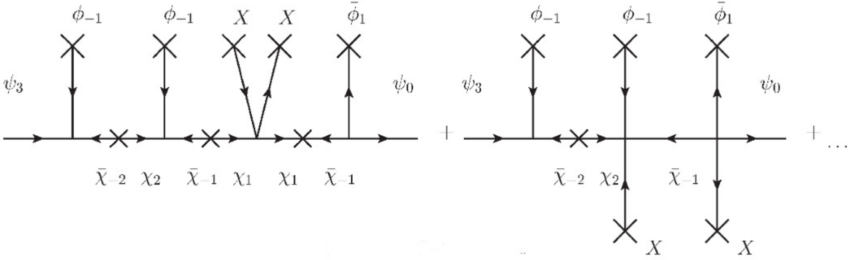

$$\Downarrow$$

$$\boxed{\left(m^2_{\tilde{\psi}}\right)_{ij} = n\ m_0^2 \times \left(\frac{\theta_i \theta_j^\dagger}{M^2}\right)}$$

Abelian Flavour symmetry

- "Simple" Abelian model with charges

$$Q_1 \sim 3, \quad Q_2 \sim 2, \quad Q_3 \sim 0, \quad d_1^c \sim 1, \quad d_2^c \sim 0, \quad d_3^c \sim 0,$$
$$u_1^c \sim 3, \quad u_2^c \sim 2, \; u_3^c \sim 0, \; \phi_1 \sim -1 \;\text{ with }\; \frac{\langle\phi_1\rangle}{M} = \lambda_c$$

- Yukawa couplings proportional to: $Y_{ij} = (\langle\phi_1\rangle/M)^{(q_1^i + q_1^j)}$

$$M^d = \langle H_1 \rangle \begin{pmatrix} \lambda^4 & \lambda^3 & \lambda^3 \\ \lambda^3 & \lambda^2 & \lambda^2 \\ \lambda & 1 & 1 \end{pmatrix}, \quad M^u = \langle H_2 \rangle \begin{pmatrix} \lambda^6 & \lambda^5 & \lambda^3 \\ \lambda^5 & \lambda^4 & \lambda^2 \\ \lambda^3 & \lambda^2 & 1 \end{pmatrix}.$$

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- Trilinear couplings::

$$Y_d^A = \begin{pmatrix} 9\lambda^4 & 7\lambda^3 & 7\lambda^3 \\ 7\lambda^3 & 5\lambda^2 & 5\lambda^2 \\ 3\lambda & 1 & 1 \end{pmatrix},\quad Y_u^A = \begin{pmatrix} 13\lambda^6 & 11\lambda^5 & 7\lambda^3 \\ 11\lambda^5 & 9\lambda^4 & 5\lambda^2 \\ 7\lambda^3 & 5\lambda^2 & 1 \end{pmatrix}.$$

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$\Longrightarrow$ **In SCKM basis trilinear couplings not diagonalized, preserve the structure of Yukawas in flavour basis!!!**

- Soft mass coupling $\phi_i^\dagger \phi_i$ invariant under all symmetries
  $\Longrightarrow$ flavour diagonal soft masses allowed by flavour symmetry

- Diagonal masses equal with single F_x as required by phenomenology

- After symmetry breaking offdiagonal entries proportional to flavon vevs, $M_{ij}^2 = m_0^2 \left(\langle\phi_1\rangle/M\right)^{|q_1^i - q_1^j|}$

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$$M^2_{\tilde{Q}} \sim M^2_{\tilde{U}_R} \sim M^2_{\tilde{D}_R} \sim m_0^2 \begin{pmatrix} 1 & 6\,\lambda^3 & 6\,\lambda^3 \\ 6\,\lambda^3 & 1 & \lambda^2 \\ 6\,\lambda^3 & \lambda^2 & 1 \end{pmatrix}$$

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- After canonical normalization:

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Discrete Non-Abelian symmetries: $\Delta(27)$

- $\Delta(27)$, Z_2, $U(1)_{\rm FN}$, $U(1)_R$, charges for leptons:

Field	ℓ,ν	ℓ^c,ν^c	$H_{u,d}$	Σ	ϕ_{123}	ϕ_1	$\bar\phi_3$	$\bar\phi_{23}$	$\bar\phi_{123}$
$\Delta(27)$	**3**	**3**	**1**	**1**	**3**	**3**	$\bar{\mathbf{3}}$	$\bar{\mathbf{3}}$	$\bar{\mathbf{3}}$
Z_2	1	1	1	1	1	-1	-1	-1	-1
$U(1)_{FN}$	0	0	0	2	-1	-4	0	-1	1
$U(1)_R$	1	1	0	0	0	0	0	0	0

$$\langle\bar\phi_3\rangle = \upsilon_3\,(0,0,1),\ \langle\,\bar\phi_{23}\rangle = \upsilon_{23}\,(0,-1,1),\ \langle\bar\phi_{123}\rangle = \upsilon_{123}\,(1,1,1)$$

- Higgs couplings, $\frac{\upsilon_3}{\Lambda} \simeq \sqrt{y_\tau}$, $\frac{\upsilon_{23}}{\Lambda} \simeq \sqrt{y_\tau}\varepsilon$, $\frac{\upsilon_{123}}{\Lambda} \simeq \sqrt{y_\tau}\varepsilon^2$:

$$Y_\ell \sim y_\tau \begin{pmatrix} \varepsilon^8 & -\varepsilon^3 & \varepsilon^3 \\ -\varepsilon^3 & 3\,\varepsilon^2 & -3\varepsilon^2 \\ \varepsilon^3 & -3\,\varepsilon^2 & 1 \end{pmatrix},\quad A_\ell \sim y_\tau\, a_0 \begin{pmatrix} 13\,\varepsilon^8 & -5\,\varepsilon^3 & 5\,\varepsilon^3 \\ -5\,\varepsilon^3 & 21\,\varepsilon^2 & -21\,\varepsilon^2 \\ 5\,\varepsilon^3 & -21\,\varepsilon^2 & 5 \end{pmatrix}$$

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- After canonical normalization and SCKM basis:

$$m^2_{\ell,R} \sim m_0^2 \begin{pmatrix} 1 & -9 y_\tau\, \varepsilon^3 & 9 y_\tau\, \varepsilon^3 \\ -9 y_\tau\, \varepsilon^3 & 1 + y_\tau \varepsilon^2 & 2 y_\tau\, \varepsilon^2 \\ 9 y_\tau\, \varepsilon^3 & 2\, y_\tau\, \varepsilon^2 & 1 + y_\tau \end{pmatrix}$$

Lepton Flavour Violation

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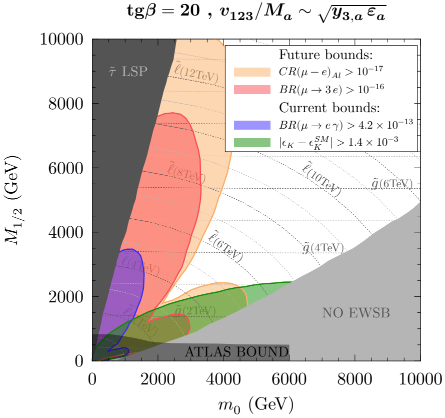

Present bounds on $\mu \to e\gamma$, $\mu \to 3e$, and ε_K, gray rectangle LHC.

Conclusions

- Flavour symmetries solve the CP and flavour problems both in New Physics (SUSY) and in the SM.
- New flavour structures will provide valuable information on the origin of flavour
- In SUSY, non-universality always present in soft-breaking terms.
- Flavour structures of soft masses and trilinears remember structures in flavour basis.
- Large reach of flavour observables in realistic flavour models, beyond LHC.
- Lepton Flavour Violation and Kaon sector very sensitive to SUSY flavour structures.