Flavor violation and CP violation in BSM extensions

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Taller: "Más allá del Modelo Estándar y Astropartćulas"

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Outline

① **Flavor Violation BSM**

➤ FV in Supersymmetry

➤ Phenomenological consequences on charged lepton sector.
$BR(\tau \to \mu\gamma)$.
$BR(h^0 \to \mu\tau)$.
$\not{F}\not{V}$ contributions to $(g-2)$.

② $\not{C}\not{P}$ **in extended Higgs sector**.
$\leadsto$ 2HDM.
$\leadsto$ non-CP-MSSM.

Susy Flavor Violation Motivation

Eventhough the increment in particle spectrum, loop contributions to EW ρ parameter is safely achieved.

Search for possible SUSY flavor structure in low-energy SUSY model in order to test it in **EW precision data** results.
We may obtain flavor non-conserving 1-loop processes within an MSSM flavor extended model:

① Leptonic sector

- Susy loop contributions to lepton flavor violation processes $\tau \to \mu\gamma$, $\mu \to e\gamma$.
- $\not{FV}$ extra contributions to muon's anomalous magnetic moment .
- neutrino mixing.

Hisano et. al. 95-96, Okada et. al. 00, Calvalho et.al. 01, ② Quark sector

- d-type quark $\not{F}\not{V}$ as $b \to s\gamma$.
- u-type quark $\not{F}\not{V}$ as $t \to c\gamma$.
  Okomura and Roszkowski 03, K.Olive and L. Velasco-Sevilla 08

③ Higgs sector

- Sfermion FV leading to extra radiative corrections to Higgs mass.
  Arana-Catania et.al 12, Bertuzzo 13

EW precision leptonic phenomenology effects

SUSY LFV contributions to EW presicion data manifest at one-loop level

① The contribution to *Lepton Flavor Violation* from sleptons 1-loop diagram:

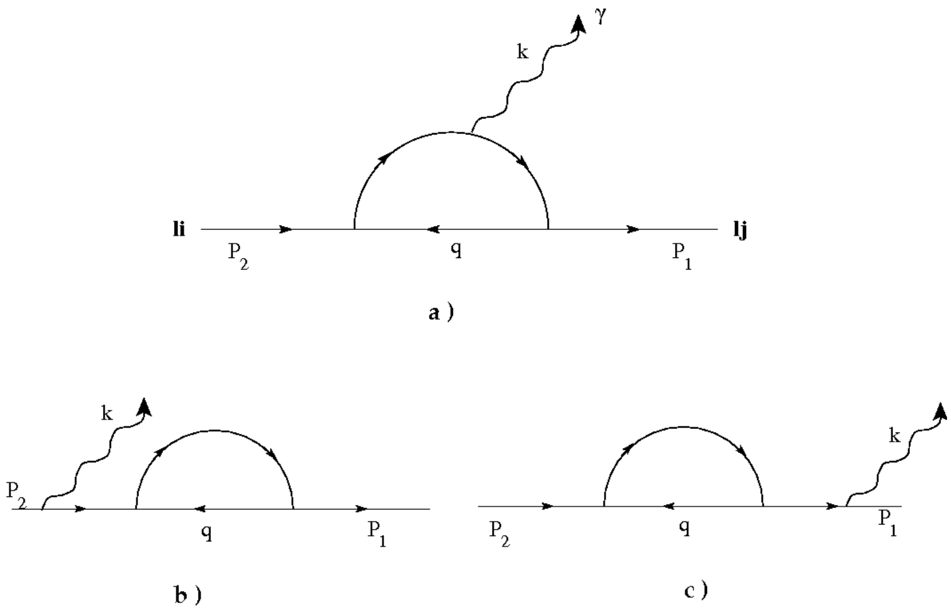


Figure 1: $\tau \to \mu\gamma$ *SUSY contribution.*

EW presicion leptonic phenomenology effects

② LFV contribution to the anomalous magnetic moment of the muon:

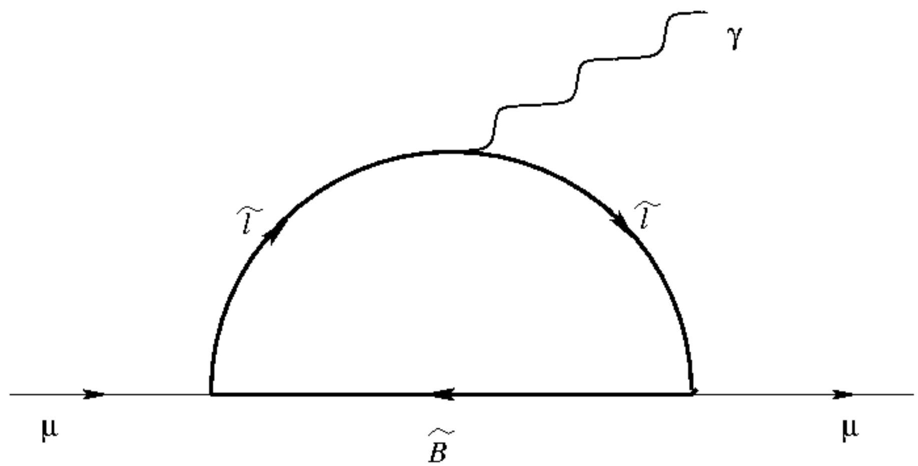


Figure 2: *muon's anomalous magnetic moment SUSY FV contribution.*

Supersymmetry

Symmetry relates fermions to bosons $\rightsquigarrow$ SUSY uses superfields (chiral and vector) to describe all particles and interactions.

Straightforward phenomenological consequence $\rightsquigarrow$ Duplicates the particle spectrum.

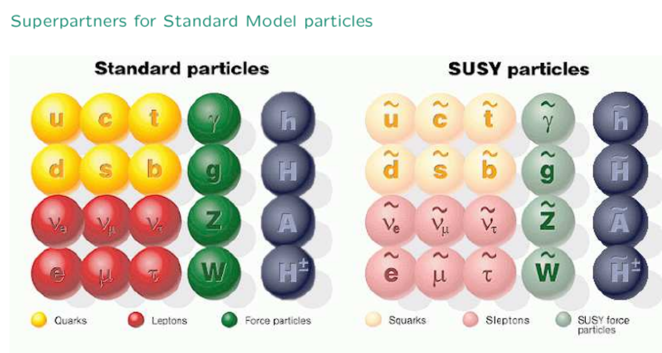
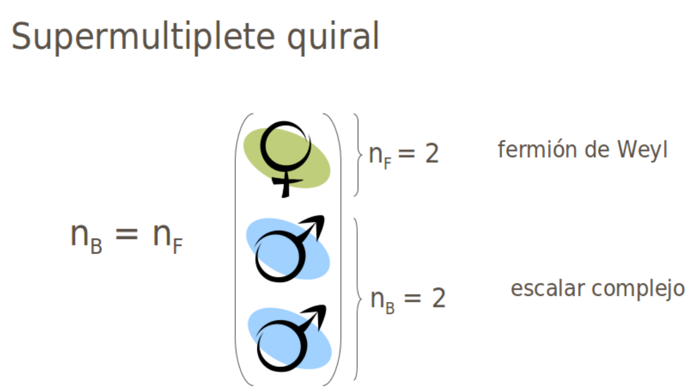


Figure 3: *Almost half of the Supersymmetry spectrum already found.*

$\rightsquigarrow$ **Susy most be broken introducing** *Soft Susy Lagrangian*.

Supersymmetry field structure for fermions

Supermultiplets:
Each of the fermion is accompanied by a complex scalar $\longrightarrow$ *chiral superfield.*



$\rightsquigarrow$ *fermions and sfermions*

Higgsinos and Higgs

Figure 4: *Quiral supermultipletes: equal fermionic and bosonic d.o.f.*

And also each of the gauge boson fields is added by a fermionic field $\longrightarrow$ *vector superfield.*

Once SUSY is broken we need to add no-dynamical fields components F and D in order to conserved the fermionic-bosonic degrees of freedom.

Higgs sector of the MSSM

Two complex SU(2) Higgs doublets:

$$H_1 = \begin{pmatrix} v_1 + \frac{1}{\sqrt{2}}(\phi_1 - i\chi_1) \\ -\phi_1^- \end{pmatrix}, \quad H_2 = \begin{pmatrix} \phi_2^+ \\ v_2 + \frac{1}{\sqrt{2}}(\phi_2 + i\chi_2) \end{pmatrix}$$

$H_1 \to d - type$ quarks $\qquad\qquad$ $H_2 \to u - type$ quarks

Physical Higgs particle spectrum :

ϕ_i , $CP = 1 \to$ two scalar fields: h^0, H^0,

χ_i , $CP = -1 \to$ one pseudoscalar field: A^0.

and

$\phi^{\pm}$, $\to$ two charged fields: $H^{\pm}$

SSB: Assuming the scalar fields to develop nonzero vacuum expectation values that break $SU(2)_L$

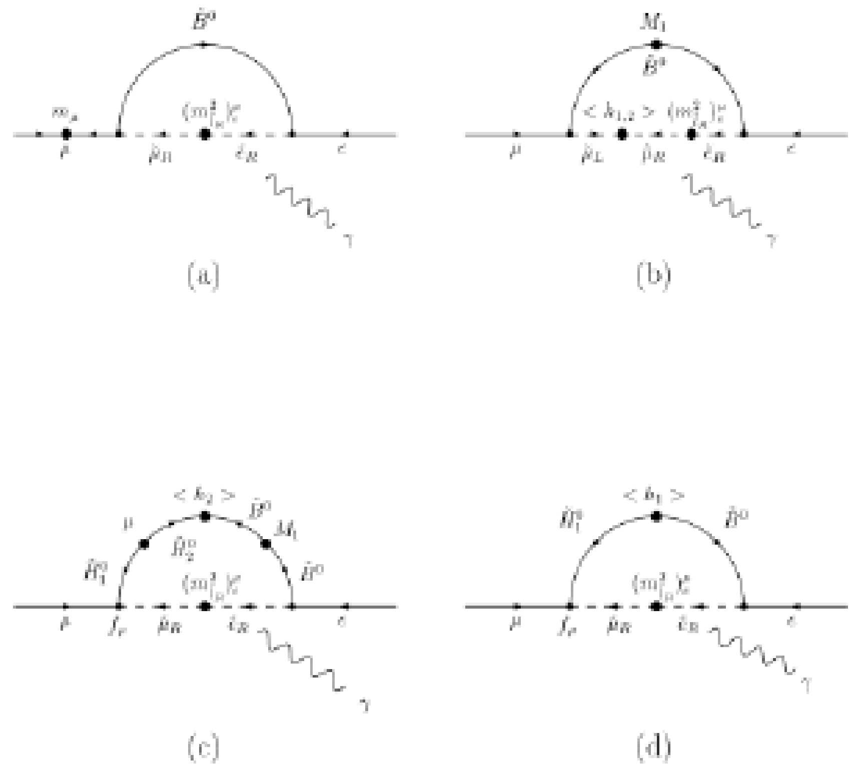
$$< H_1 >= v_1 \begin{pmatrix} 1 \\ 0 \end{pmatrix}, \qquad < H_2 >= v_2 \begin{pmatrix} 0 \\ 1 \end{pmatrix} \tag{1}$$

Discrete symmetry is set to the Yukawa sector:

Pioneers on Lepton Flavor Violations in MSSM using MIA

Using a qualitative aproximation in the flavor basis, known as *Mass Insertion Approximation (MIA)*,

J. Hisano, T. Moroi, K. Tobe and M. Yamaguchi, Phys. Lett. B 391, 341 (1997)



Lepton Flavor Violations in MSSM using MIA

The MIA takes the diagonal part of the flavour mass matrix is absorbed into a definition on an unphysical massive propagator and the non-diagonal parts commonly referd to as mass insertions is treated perturbatively, as part of the interaction Lagrangian.

Dedes, Paraskevas, Rosiek, Suxho, Tamvakis 2015

"The MIA is a Taylor expansion only with respect ...(to) the mass-squared difference. A small off-diagonal element does not necessarily imply a small mass difference. Instead, it may be related to small mixing angles. But then the validity of the MIA is questionable."

Guy Raz 2002

$\not{SUSY} \to$ *Soft-terms of MSSM*

Soft SUSY Lagrangian

Kuroda 99

$$\mathcal{L}_{soft}^{MSSM} = \mathcal{L}_{gauginogluino}^{mass} - \mathcal{L}_{sfermion}^{mass} - \mathcal{L}_{Higgs} - \mathcal{L}_{trilinear} \qquad (2)$$

with

$$-\mathcal{L}_{gauginogluino}^{mass} = \frac{1}{2}\left[M_1\tilde{B}\tilde{B} + M_2\sum_{a=1}^{3}\tilde{W}^a\tilde{W}_a + M_3\sum_{a=1}^{8}\tilde{G}^a\tilde{G}_a + h.c.\right] \qquad (3)$$

$$-\mathcal{L}_{sfermion}^{mass} = \sum_{i=gen} m_{\tilde{Q}_i}^2\tilde{Q}_i^\dagger\tilde{Q}_i + m_{\tilde{L}_i}^2\tilde{L}_i^\dagger\tilde{L}_i + m_{\tilde{u}i}^2|\tilde{u}_{Ri}| + m_{\tilde{d}i}^2|\tilde{d}_{Ri}|^2 + m_{\tilde{l}i}^2|\tilde{l}_{Ri}|^2 \quad (4)$$

$$-\mathcal{L}_{Higgs} = m_1^2H_1^\dagger H_1 + m_2^2H_2^\dagger H_2 + \mu B(H_2.H_1 + h.c.) \qquad (5)$$

$$-\mathcal{L}_{trilinear} = \sum_{i,j=gen}\left[A_{ij}^u\tilde{Q}_iH_2\tilde{u}_{Rj}^* + A_{ij}^u\tilde{Q}_iH_1\tilde{d}_{Rj}^* + A_{ij}^l\tilde{L}_iH_1\tilde{l}_{Rj}^*\right] \qquad (6)$$

1. $BR(\tau \to \mu\gamma)$ no-MIA

The Lagrangian $\tilde{B}^0\tilde{l}l$ in mass eigenstate now is given by:

$$
\begin{aligned}
\mathcal{L}_{\tilde{B}\tilde{l}l} \quad = \quad & -\frac{g}{2\sqrt{2}}\tan\theta_W \bar{\tilde{B}}\Big\{ \left[-P_L\tilde{e}_1 + 2P_R\tilde{e}_2\right] e + \\
& -\frac{s_\varphi}{\sqrt{2}}\left[(1+3\gamma_5)\tilde{\mu}_1 + (3+\gamma_5)\tilde{\mu}_2\right]\mu + \\
& +\frac{c_\varphi}{\sqrt{2}}\left[(1+3\gamma_5)\tilde{\mu}_1 + (3+\gamma_5)\tilde{\mu}_2\right]\tau + \\
& +\frac{c_\varphi}{\sqrt{2}}\left[(3+\gamma_5)\tilde{\tau}_1 + (1+3\gamma_5)\tilde{\tau}_2\right]\mu + \\
& +\frac{s_\varphi}{\sqrt{2}}\left[(3+\gamma_5)\tilde{\tau}_1 + (1+3\gamma_5)\tilde{\tau}_2\right]\tau \Big\}
\end{aligned} \qquad (7)
$$

We may write the coupling as

$$
g_{l_i B\tilde{l}_r} = -\frac{g\tan\theta_W}{4}[S_{l_i,\tilde{l}_r} + P_{l_i,\tilde{l}_r}\gamma^5]
$$

1. $BR(\tau \to \mu\gamma)$ gauge invariance

The total amplitude is written as follows:

$$\begin{aligned} \mathcal{M}_T &= \bar{u}(p_1)[\imath E_{ij}\sigma^{\mu\nu}k_\nu\epsilon_\mu + \imath F_{ij}\sigma^{\mu\nu}k_\nu\epsilon_\mu\gamma^5]u(p_2) \\ &= \bar{u}(p_1)[\frac{E_{ij}}{2} + \frac{F_{ij}}{2}\gamma^5][\not{k}, \not{\epsilon}]u(p_2)\ . \end{aligned} \quad (8)$$

The Branching Ratio will be given by

$$\mathcal{BR}(\tau \to \mu\gamma) = \frac{(1-x^2)^3 m_\tau^3}{4\pi\Gamma_\tau}[|\sum_{\tilde{l}} E_{\tilde{l}}^{\tau\mu}|^2 + |\sum_{\tilde{l}} F_{\tilde{l}}^{\tau\mu}|^2]\ , \quad (9)$$

with $x = \frac{m_\mu}{m_\tau}$.

$(g-2)$ *from FV slepton loop.*

$$
\begin{aligned}
\bar{u}(p_1)\Gamma^\mu u(p_2) &= \imath g_c \bar{u}(p_1)\left[S_{\tilde{B}\mu,\tilde{l}} + P_{\tilde{B}\mu,\tilde{l}}\gamma^5\right]\frac{1}{(2\pi)^4}\int dk^4 \frac{\imath[\not{k} + m_{\tilde{B}}]}{D_t}\imath\frac{\tan\theta_{\mathrm{w}} \mathrm{g}_1}{4} \\
&\times [S_{\tilde{B}\mu,\tilde{l}} - P_{\tilde{B}\mu,\tilde{l}}\gamma^5]\frac{\imath}{D_2}\frac{\imath}{D_1}[2k + p_1 + p_2]_\mu u(p_2) \\
&= \imath g_c^2 \left[S^2_{\tilde{B}\mu,\tilde{l}} - P^2_{\tilde{B}\mu,\tilde{l}}\right] m_{\tilde{B}} \bar{u}(p_1)\int \frac{dk^4}{(2\pi)^4}\frac{(2k + p_1 + p_2)^\mu}{D_t D_1 D_2} u(p_2) \\
&+ g_c^2 \bar{u}(p_1)\left[S^2_{\tilde{B}\mu,\tilde{l}} + P^2_{\tilde{B}\mu,\tilde{l}}\right]\int \frac{dk^4}{(2\pi)^4}\frac{(2k + p_1 + p_2)^\mu \not{k}}{D_t D_1 D_2} u(p_2) + \ldots \\
&= g_c^2 \bar{u}(p_1)\left[(S^2_{\tilde{B}\mu,\tilde{l}} - P^2_{\tilde{B}\mu,\tilde{l}}) m_{\tilde{B}} B_1^\mu(q^2)\right] u(p_2) \\
&+ g_c^2 \bar{u}(p_1)\left[(S^2_{\tilde{B}\mu,\tilde{l}} + P^2_{\tilde{B}\mu,\tilde{l}}) B_2^\mu(q^2)\right] u(p_2) + \ldots, \qquad (10)
\end{aligned}
$$

where $q^2 = (p_2 - p_1)^2$ and the ellipsis means terms that are not involved in the determination of the anomaly contribution.

The propagators are given by

$$Dt = \frac{1}{k^2 - m_{\tilde{B}}^2} \ , \tag{11}$$

$$D_1 = \frac{1}{(p_1 + k)^2 - m_{\tilde{l}}^2} \ , \tag{12}$$

$$D_2 = \frac{1}{(p_2 + k)^2 - m_{\tilde{l}}^2} \ . \tag{13}$$

$$a_\mu = \frac{g_c^2 m_\mu}{(4\pi)^2} \left[(S^2_{\tilde{B}\mu,\tilde{l}} + P^2_{\tilde{B}\mu,\tilde{l}}) \frac{m_\mu}{6 m_{\tilde{l}}^2} F_1^N(x) - (S^2_{\tilde{B}\mu,\tilde{l}} - P^2_{\tilde{B}\mu,\tilde{l}}) \frac{m_{\tilde{B}}}{3 m_{\tilde{l}}^2} F_2^N(x) \right], \tag{14}$$

here $x = m_{\tilde{B}}^2 / m_{\tilde{l}}^2$ and, for brevity we define $g_c^2 = \frac{\tan^2\theta_{\rm w} g_1^2}{16}$. We have used the notation for the functions $F_{1,2}^N(x)$ given in Ref.Stockinger:2006zn.

$h^0 \to \tau\mu$ *FV slepton loop.*

the slepton which interacts with the muon (tau) is labeled with the index i (j), see Fig 1.

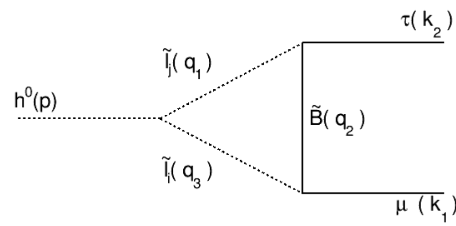
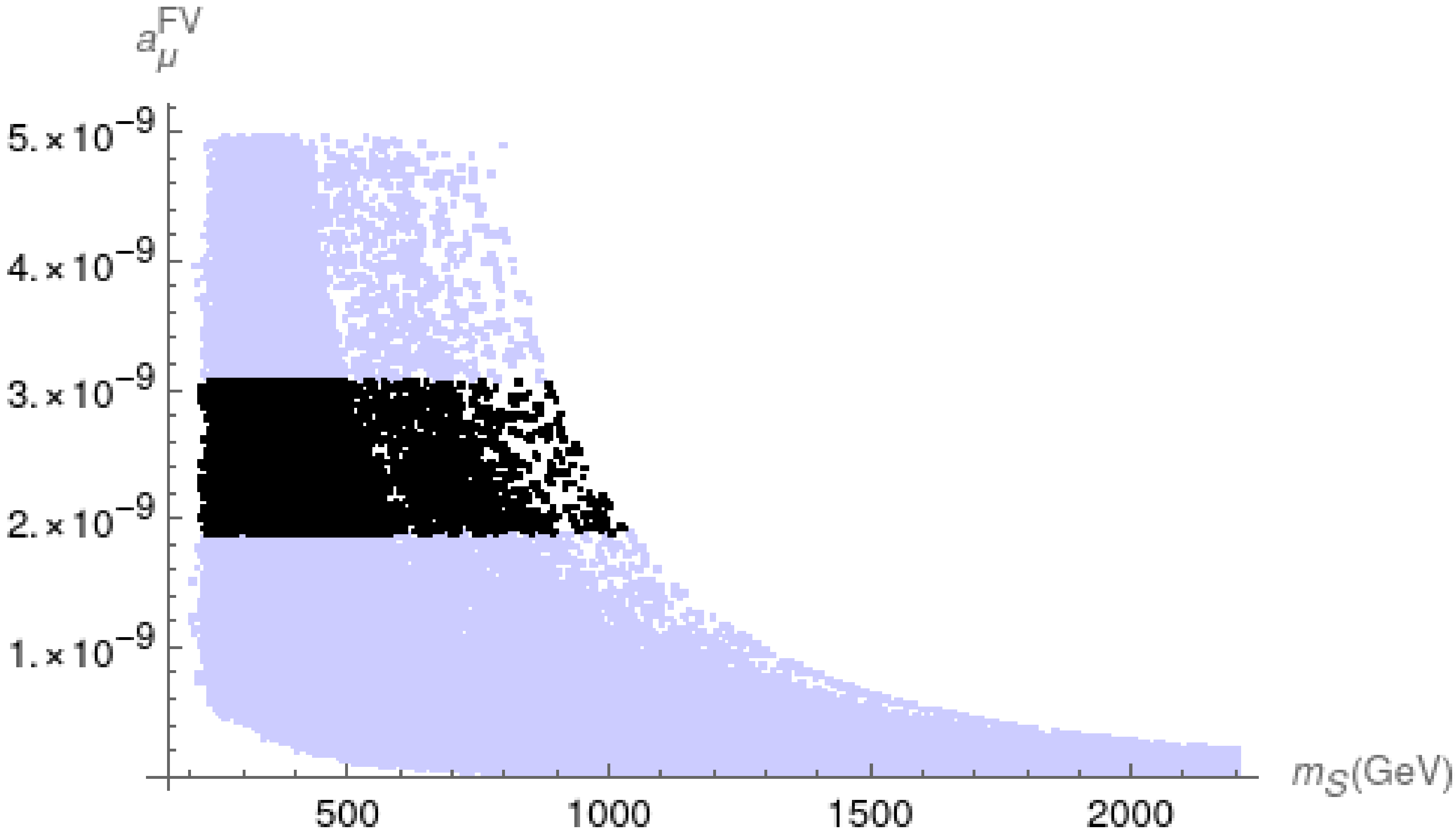


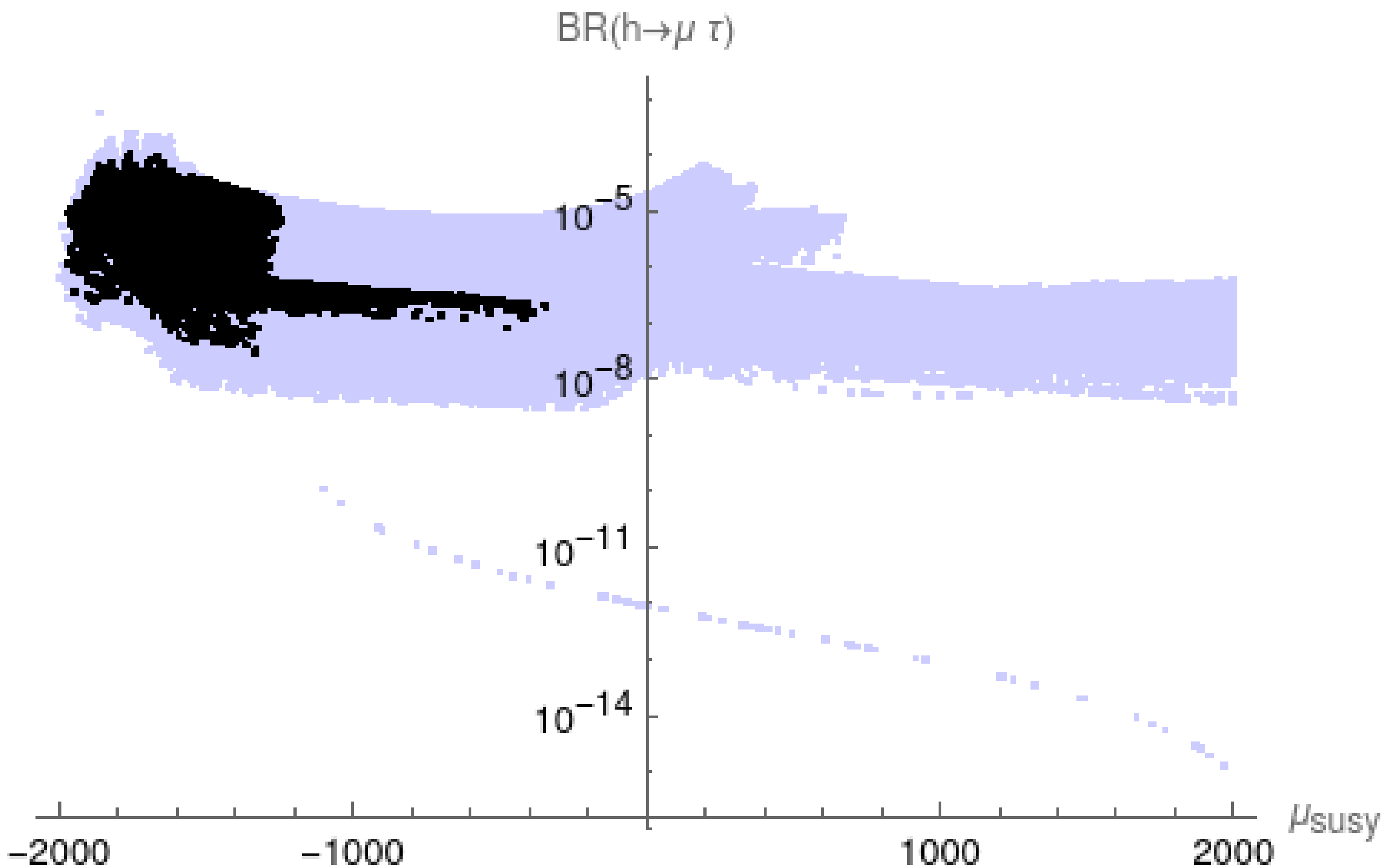
Figure 5: *1-loop SUSY slepton flavor mixing contribution to* $h^0 \to \mu\tau$.

The notation used for the coupling between the bino $\tilde{B}$, the slepton $\tilde{l}$ and the lepton l, for $l = \mu, \tau$, which is denoted as $\tilde{B}\tilde{l}l$, can be written in terms of three types of coefficients for each lepton.

Preliminary Results $BR(h^0 \to \mu\tau)$



Preliminary Results $BR(h^0 \to \mu\tau)$



Preliminary Results: No-FV limit

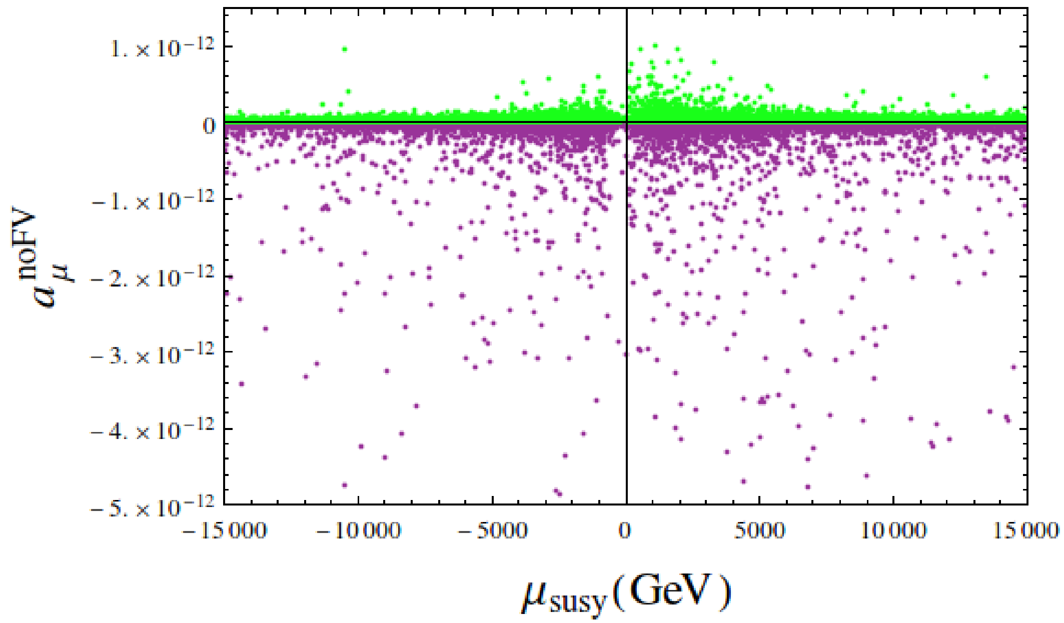


Figure 6: Complete Bino-smuon loop contribution on MSSM with no flavour violation to $g-2$, considering $A_0 = 0$ green points (lighter), and running A_0 for $(50, 5000)\ GeV$ purple points (darker).

Higgs sector of the 2HDM with CP non-invariance I

The most general form of a two $SU(2)$ Higgs doublet model potential (2HDM) with CP violation is

$$\begin{aligned}\mathcal{L}_V &= \mu_1^2(\Phi_1^\dagger\Phi_1) + \mu_2^2(\Phi_2^\dagger\Phi_2) + m_{12}^2(\Phi_1^\dagger\Phi_2) + \lambda_1(\Phi_1^\dagger\Phi_1)^2 \\ &+\lambda_2(\Phi_2^\dagger\Phi_2)^2 + \lambda_3(\Phi_1^\dagger\Phi_1)(\Phi_2^\dagger\Phi_2) + \lambda_4(\Phi_1^\dagger\Phi_2)(\Phi_2^\dagger\Phi_1) \\ &+\lambda_5(\Phi_1^\dagger\Phi_2)^2 + [\lambda_6(\Phi_1^\dagger\Phi_1) + \lambda_7(\Phi_2^\dagger\Phi_2)](\Phi_1^\dagger\Phi_2) + h.c.\end{aligned} \tag{15}$$

where $\Phi_{1,2}$ denote two complex $Y=1,\ SU(2)_L$, iso-doublet scalar fields.

$\not{C}\not{P} - 2HDM$ Higgs masses

Las segundas derivadas se obtiene la matriz de masa

$$M_{ij}^2 = \begin{pmatrix} M_{12} & M_{12} & M_{13} & M_{14} & 0 & 0 & 0 & 0 \\ M_{21} & M_{22} & M_{23} & M_{24} & 0 & 0 & 0 & 0 \\ M_{31} & M_{32} & M_{33} & M_{34} & 0 & 0 & 0 & 0 \\ M_{41} & M_{42} & M_{43} & M_{44} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & M_{55} & M_{56} & 0 & M_{58} \\ 0 & 0 & 0 & 0 & M_{65} & M_{66} & M_{67} & 0 \\ 0 & 0 & 0 & 0 & 0 & M_{76} & M_{77} & M_{78} \\ 0 & 0 & 0 & 0 & M_{85} & 0 & M_{87} & M_{88} \end{pmatrix}. \qquad (16)$$

2HDM Elementos de la matriz de masa con $\not{C}\not{P}$

Los valores de los componentes de la matriz neutra son los siguientes:

$$M_{11} = 12v_1^2\lambda_1 + v_2^2\lambda_R + 3v_1v_2(\lambda_6 + \lambda_6^*) + 2\mu_1^2$$

$$M_{12} = \frac{1}{2}[4v_1v_2\lambda_R + 3v_1^2(\lambda_6 + \lambda_6^*) + 3v_2^2(\lambda_7 + \lambda_7^*) - 2(\mu_{12}^2 + {\mu_{12}^*}^2)]$$

$$M_{13} = -i(v_2^2(\lambda_5 - \lambda_5^*) + v_1v_2(\lambda_6 - \lambda_6^*))$$

$$M_{14} = \frac{1}{2}i[(4v_1v_2(\lambda_5 - \lambda_5^*) + 3v_1^2(\lambda_6 - \lambda_6^*) + v_2^2(\lambda_7 - \lambda_7^*) - 2(\mu_{12} - {\mu_{12}^*}^2)]$$

$$M_{22} = 12v_2^2\lambda_2 + v_1^2\lambda_R + 3v_1v_2(\lambda_6 + \lambda_6^*) + 2\mu_2^2$$

$$M_{23} = -\frac{1}{2}i[(4v_1v_2(\lambda_5 - \lambda_5^*) + v_1^2(\lambda_6 - \lambda_6^*) + 3v_2^2(\lambda_7 - \lambda_7^*) - 2(\mu_{12} - {\mu_{12}^*}^2)]$$

$$M_{24} = iv_1(v_1(\lambda_5 - \lambda_5^*) + v_2(\lambda_7 - \lambda_7^*))$$

$$M_{31} = -iv_2(v_2(\lambda_5 - \lambda_5^*) + v_1(\lambda_7 - \lambda_7^*))$$

$$M_{33} = 4v_1^2\lambda_1 + v_2^2(\lambda_R - 2(\lambda_5 + \lambda_5^*)) + v_1v_2(\lambda_6 + \lambda_6^*) + 2\mu_1^2$$

$$M_{34} = \frac{1}{2}[(4v_1v_2(\lambda_5 + \lambda_5^*) + v_1^2(\lambda_6 + \lambda_6^*) + v_2^2(\lambda_7 + \lambda_7^*) - 2(\mu_{12} + {\mu_{12}^*}^2)]$$

$$M_{44} = 4v_2^2\lambda_2 + v_1^2(\lambda_R - 2(\lambda_5 + \lambda_5^*)) + v_1v_2(\lambda_7 + \lambda_7^*) + 2\mu_2^2$$

Higgs sector in the Minimal Supersymmetric Extension of the Standard Model with CP

The radiative suppression establishes a hierarchy on the couplings. At tree level, without radiative corrections, the couplings have a discrete symmetry which gives the following values

$$\mu_1^2 = -m_1^2 - |\mu|^2, \qquad \mu_2^2 = -m_2^2 - |\mu|^2, \qquad \lambda_1 = \lambda_2 = -\frac{1}{8}(g_w^2 + g'^2),$$
$$\lambda_3 = -\frac{1}{4}(g_w^2 - g'^2), \qquad \lambda_4 = \tfrac{1}{2}g_w^2, \qquad \lambda_5 = \lambda_6 = \lambda_7 = 0.$$

But we could have complex couplings in $\mathcal{L}_V$ of the form

$$m_{12}^2 = m_{12}^{2R} + i m_{12}^{2I} \qquad \lambda_{5,6,7} = \lambda_{5,6,7}^R + i\lambda_{5,6,7}^I \tag{17}$$

At higher orders, the mixing of heavy neutral $H - A$ Higgses necessarily generates a new source of CP violation

The rotation to the known Higgs states would be given as CP-odd:

$$\begin{aligned} G^0 &= A_1 \cos\beta + A_2 \sin\beta \\ A^0 &= -A_1 \sin\beta + A_2 \cos\beta \end{aligned} \tag{18}$$

CP-even:

$$\begin{aligned} h^0 &= -H_1 \sin\alpha + H_2 \cos\alpha \\ H^0 &= H_1 \cos\alpha + H_2 \sin\alpha \end{aligned} \tag{19}$$

with $v = (v_1^2 + v_2^2)^{1/2} \approx 246\ GeV.$

Neutral Higgs bosons mass matrix $\mathcal{M}^2(s)$ in the $\not{C}\not{P}$ 2HDM

- The mass matrix $\mathcal{M}_0^2$ of neutral Higgs fields in the basis of $h,\ H$ and A which is hermitian and symmetric by CPT invariance is readily derived from $\mathcal{L}_V$

$$\mathcal{M}_0^2 = v^2 \begin{pmatrix} \lambda & -\hat{\lambda} & -\hat{\lambda}_p \\ -\hat{\lambda} & \lambda - \lambda_A + \frac{1}{v^2}M_A^2 & -\lambda_p \\ -\hat{\lambda}_p & \lambda_p & \frac{1}{v^2}M \end{pmatrix} \tag{20}$$

The $\lambda, \hat{\lambda}$ and λ_A are functions of the $Re\lambda_i$ while λ_p and $\hat{\lambda}_p$ are functions of the $Im\lambda_i$ in $\mathcal{L}_V$

- For small mass differences, the mixing of the states is strongly affected by their widths. Thefore, the Hermitian matrix $\mathcal{M}_0^2$ has to be supplemented by the antihermitian part $-iM\Gamma(s)$ incorporating the decay matrix

$$\mathcal{M}^2(s) = \mathcal{M}_0^2 - iM\ \Gamma(s) \tag{21}$$

Higgs Masses in a CP Non-invariant Higgs Sector

- In a CP non-invariant Higgs sector of the THDM, the three neutral scalar bosons, H_1,H_2 and H_3, mix and form a triplet with CP-even and CP-odd components in their wave functions.

- The 3×3 mass matrix, $\mathcal{M}^2 = \mathcal{M}_R^2 - iM\Gamma$ is non-Hermitian using the 2HDM notation for the mass matrix

$$\mathcal{M}_R^2 = v^2 \begin{pmatrix} \lambda & 0 & -\hat{\lambda}_p \\ 0 & m_A^2 - \lambda - \lambda_A & \lambda_p \\ -\hat{\lambda}_p & \lambda_p & m_A^2 \end{pmatrix} . \tag{22}$$

- In the decoupling limit,

$$M_A^2 >> |\lambda_i| v^2, \tag{23}$$

mixing between the light state, H_1, and the heavy Higgs states, H_2 and H_3 is small, compared with the mixing of the nearly degenerate heavy Higgs states H_2 and H_3.

- By CPT-invariance, the mass matrix $\mathcal{M}^2_{H_2,H_3}$ is symmetric.

- In the basis of the $|H\rangle$ and $|A\rangle$ states, the 2×2 submatrix is

$$\mathcal{M}^2_{H,A} = \begin{pmatrix} M_H^2 - iM_H\Gamma_H & \Delta^2_{HA} \\ \Delta^2_{HA} & M_A^2 - i\Gamma_A M_A \end{pmatrix} \tag{24}$$

..to be continued...

Thank you!

Muon magnetic moment anomaly a_μ

We know $\vec{\mu} = -g\frac{e}{2m}\vec{s}$. Which is corrected by 1-loop diagramas, for the muon

$$\vec{\mu}_\mu = \frac{e}{2m_\mu}(1 + a_\mu)\vec{\sigma}$$

The electron spin interacts with an external electromagnetic field. Using Gordon identity

$$\Gamma^\mu = A\gamma^\mu + B(p_1 + p_2)^\mu + \cdots = F_1(q^2)\gamma^\mu + \frac{i\sigma^{\mu\nu}q_\nu}{2m}F_2(q^2)$$

F are called form factors and are functions depending on $q^2 = (p_2 - p_1)^2$. The magnetic moment anomaly is defined as

$$g = 2[F_1(0) + F_2(0)] = 2 + 2F_2(0) \to a_\mu \equiv F_2(0) = \frac{g-2}{2}$$

At lowest order: $F_1 = 1$, $F_2 = 0$

$$a_\mu^{\rm SM} = a_\mu^{\rm QED} + a_\mu^{\rm EW} + a_\mu^{\rm Had} \quad . \tag{4}$$

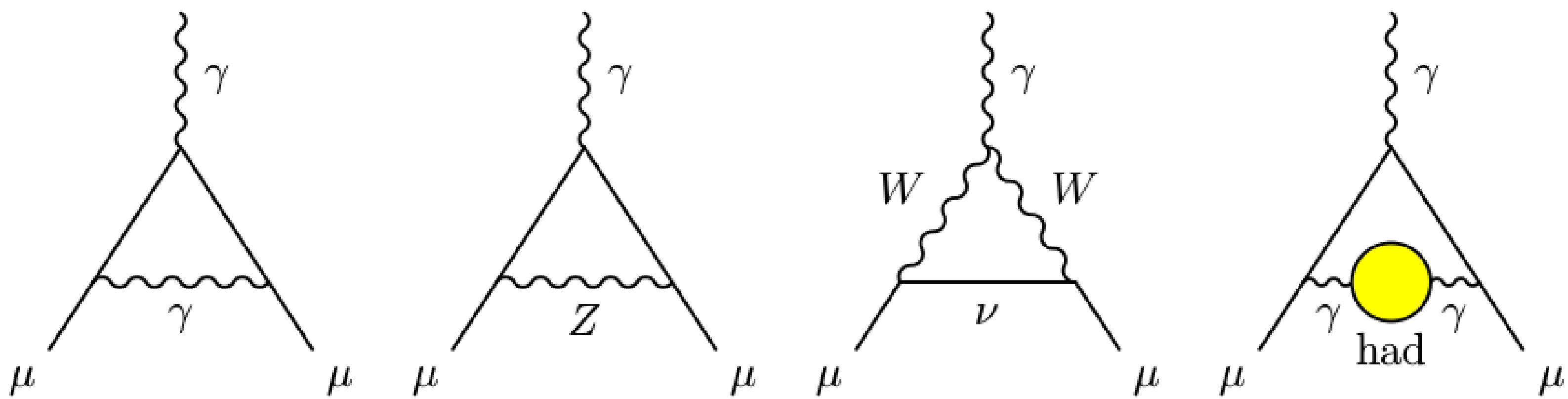


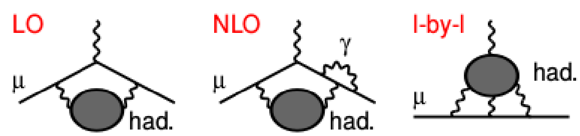
Figure 1: Representative diagrams contributing to $a_\mu^{\rm SM}$. From left to right: first order QED (Schwinger term), lowest-order weak, lowest-order hadronic.

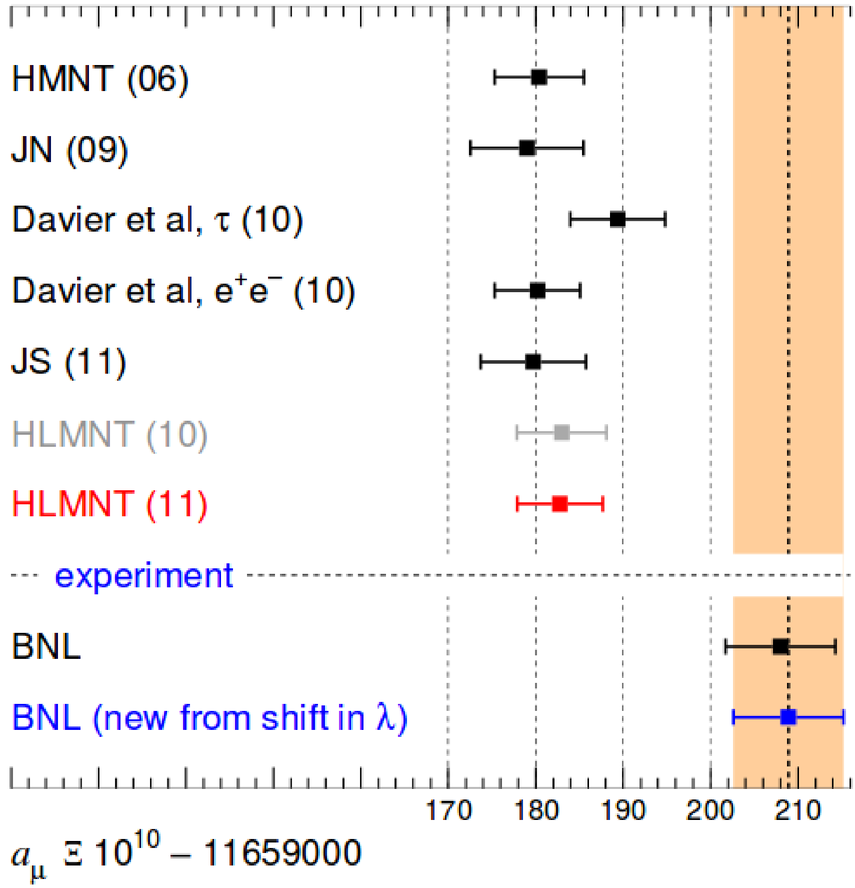
Introduction: Standard Model prediction for muon $g-2$

QED contribution	11 658 471.808 (0.015)	Kinoshita & Nio, Aoyama et al
EW contribution	15.4 (0.2)	Czarnecki et al
Hadronic contributions		
LO hadronic	**694.9 (4.3)**	HLMNT11
NLO hadronic	−9.8 (0.1)	HLMNT11
light-by-light	10.5 (2.6)	Prades, de Rafael & Vainshtein
Theory TOTAL	**11 659 182.8 (4.9)**	
Experiment	**11 659 208.9 (6.3)**	world avg
Exp − Theory	**26.1 (8.0)**	**3.3 σ discrepancy**

(in units of 10^{-10}. Numbers taken from HLMNT11, arXiv:1105.3149)

n.b.: hadronic contributions:





HLMNT=K Hagiwara, R. Liao, D. Martin, D. Nomura and T. Teubner

Reducing MSSM parameters

At tree level, the MSSM parameters could be reduced to only 2: m_A and $\tan\beta$, CMSSM.
Once we calculate one-loop radiative corrections we most set values to other parameters.

Most scenarios were built in order to have the least free parameters.
phenomenological, pMSSM

1. CP-conserving (no extra source)
2. no FCNC
3. $m_{\tilde{f}1} \approx m_{\tilde{f}2}$ to accomplish $K^0 - \bar{K}^0$ mixing

phenomenological, pMSSM

22 input parameters:

$$\tan\beta;$$
$$m_1^2, m_2^2;$$
$$M_1, M_2, M_3;$$
$$\tilde{m}_q,\ \tilde{m}_{uR}, \tilde{m}_{dR}, \tilde{m}_l, \tilde{m}_{eR};$$
$$\tilde{m}_{Qt},\ \tilde{m}_{tR}, \tilde{m}_{bR}, \tilde{m}_{L\tau}, \tilde{m}_{\tau R};$$
$$A_{u,c}, A_{d,s}, A_{e,\mu};\quad A_t, A_b, A_\tau$$

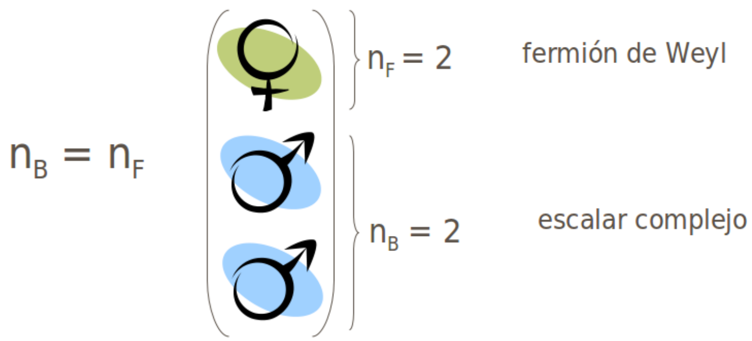
We propouse a different consideration for trilinear couplings

$$A_u, A_d, A_e;\quad A_{c,t}, A_{s,b}, A_{\mu,\tau}$$

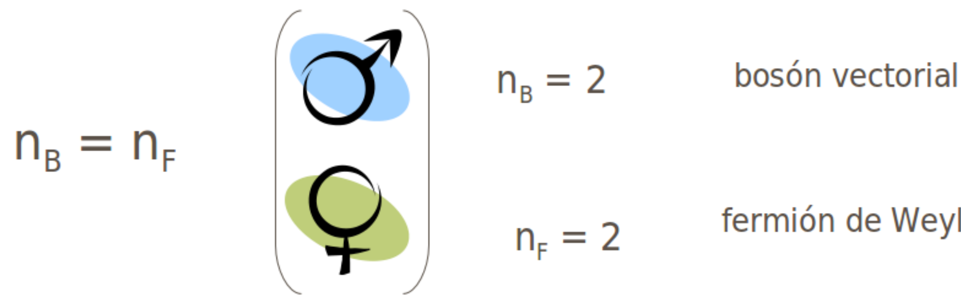
where the two families are mixed.

Supersymmetry

Supermultiplete quiral



Supermultiplete vectorial



Supersymmetry

In $MSSM$:

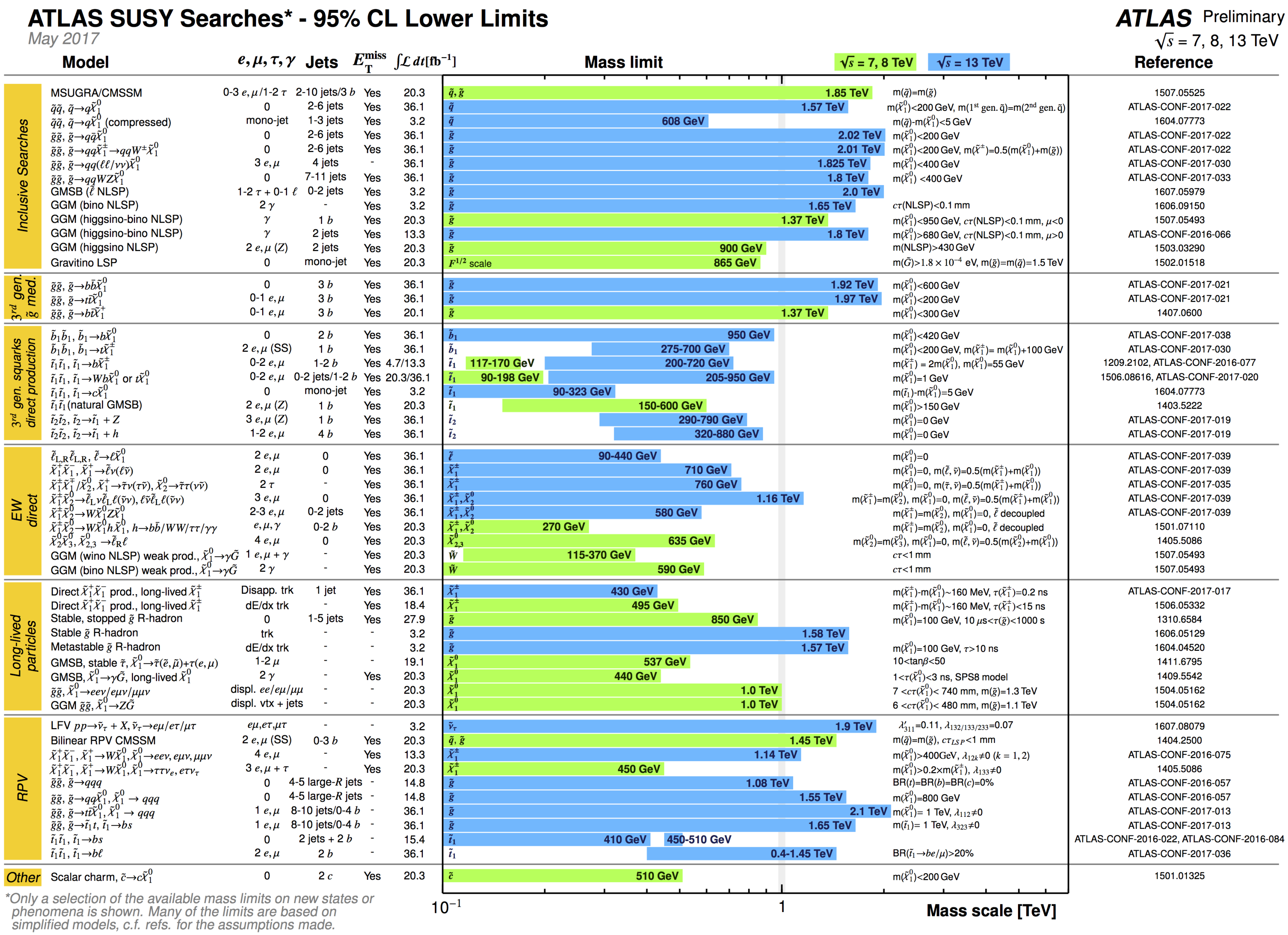
- EW scale is stabilized, with $\lambda_S = |\lambda_f|^2$ then the Λ^2_{UV} will neatly cancel

  for instance see [S.P. Martin 08, a SUSY Premier]

- Unification of gauge couplings.
- Generates DM candidates.
- Obtain FV couplings through $SUSY\ loops$
- Solution to hierarchy problem

H.Haber 95,
Low-energy Supersymmetry:Prospects and Challenges, Djouadi and Quevillon 13.

Supersymmetry experimental searches.



Supersymmetry at LHC.

In addition there are other SUSY models which may fit the current LHC data

- NUHM1 [Buchmueller et. al. 11]
- NMSSM [Benbrik et. al. 12]
- Split SUSY [Arkani-Hamed and S. Dimopoulos 05]
- High-scale SUSY [L.J. Hall and Y. Nomura 10]

$\cdots$ we may even review H. Baer and J. List 13, *Post LHC8 SUSY benchmark points for ILC physics*