Flavour in the Era of LHC

WG3 theory report

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WG3 – Lepton Flavour Violation

- L and L_i conserved in the SM – any experimental FV signal implies physics beyond SM

- Much less experimental data – oscillation measurements, leptogenesis & constraints (LFV, EDMs)

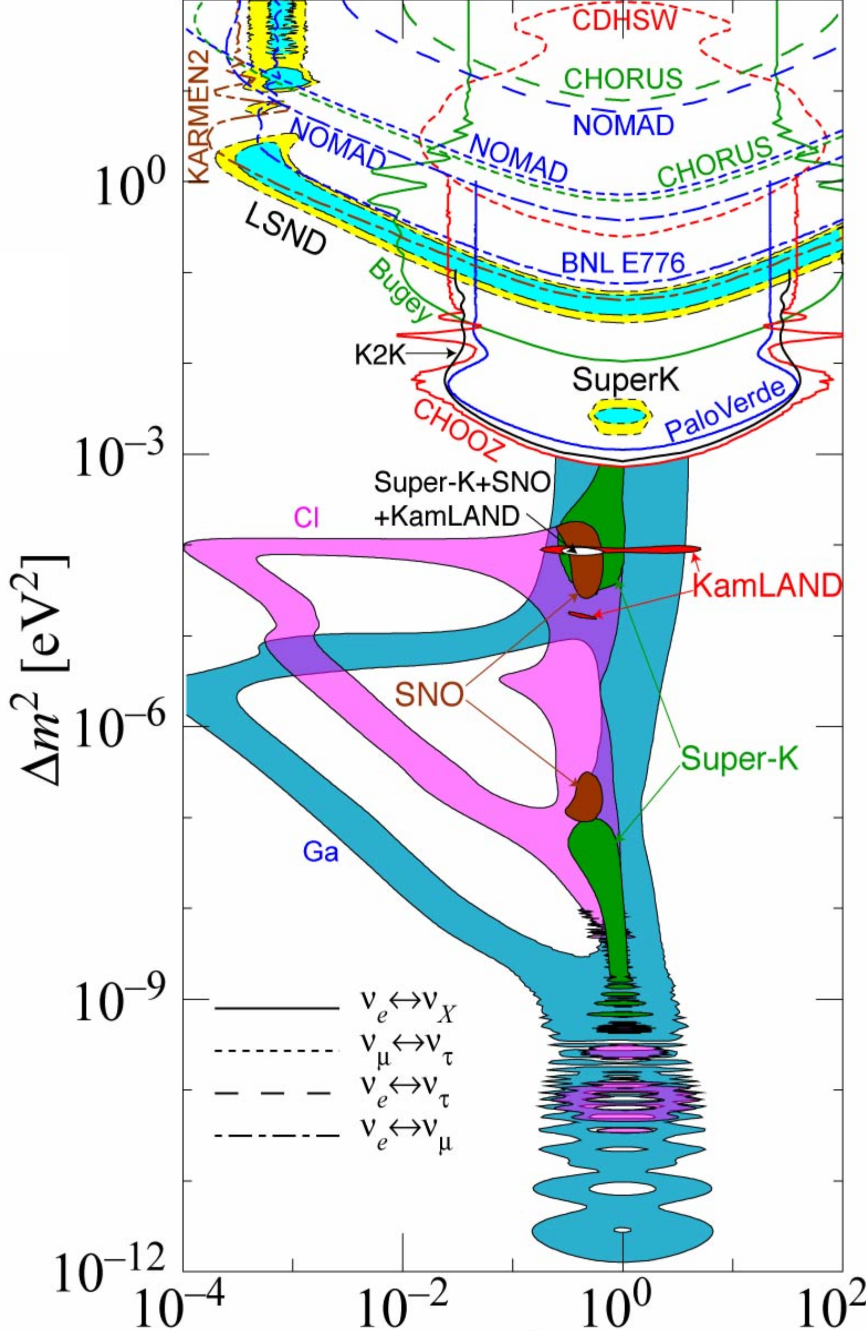
- Physics at low and high scales come together

Marco Picariello   Global fits

Three neutrino analysis

	−3σ	−2σ		+2σ	+3σ
Δm^2_{12} (10^{-5} eV^2)					
	6.9	7.2	7.9	8.7	9.0
$\sin^2\theta_{12}$					
	0.24	0.27	0.31	0.36	0.40
Δm^2_{23} (10^{-3} eV^2)					
	1.5	1.8	2.3	2.9	3.2
$\sin^2\theta_{23}$					
	0.31	0.34	0.47	0.63	0.67
$\sin^2\theta_{13}$ (10^{-2})			<	2.1	4.6

$U^T M_\nu U = \mathrm{diag}(m_1, m_2, m_3)$



2 ν analysis

http://hitoshi.berkeley.edu/neutrino

Seesaw

Why are neutrinos so light?

$$\frac{1}{2}\nu_R^{cT} M \nu_R^c + \nu_R^{cT} Y_\nu L \cdot H_2$$

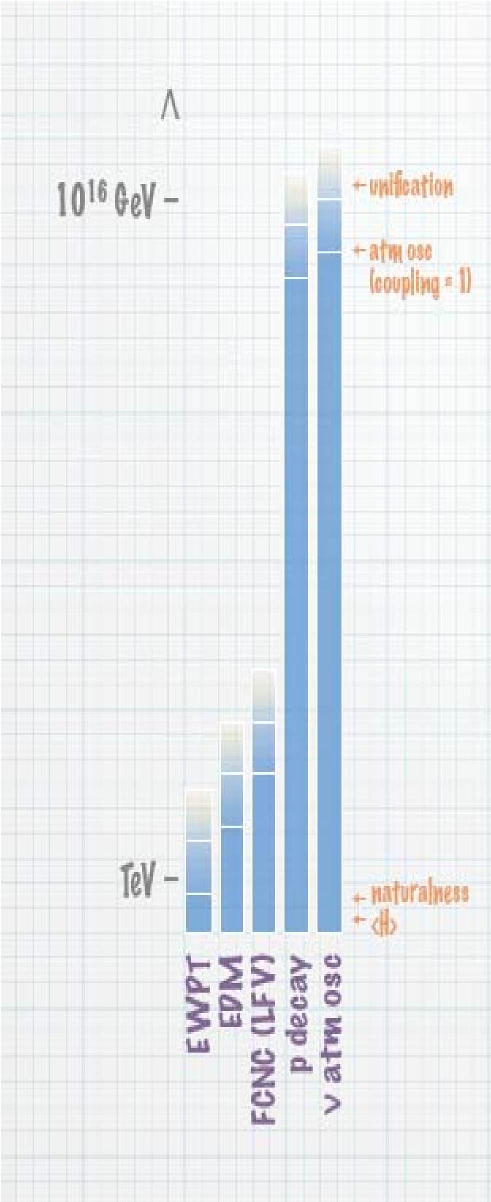
3+3+3=9 parameters

$$M_\nu = -m_D^T M^{-1} m_D$$

18 new parameters

M~10^{14} GeV

$$Y_\nu = \frac{1}{v \sin\beta} D\left(\sqrt{M_i}\right)\ R\, D\left(\sqrt{m_j}\right) U^\dagger$$



$\delta_{RR} \sim (Y_u^\dagger Y_u) \log M_P/M_{GUT}$

δ_{LL} sleptons $\Leftrightarrow$ GUT relations $\Leftrightarrow \delta_{RR}$ squarks

$\delta_{LL} \sim (Y_\nu^\dagger Y_\nu) \log M_{GUT}/M_N$

SUSY: $\frac{1}{\Lambda_{LFV}} \rightarrow \frac{1}{\tilde{m}_{SUSY}}$

δ_{LL} δ_{RR} δ_{LR} for sleptons and squarks

$\mu \rightarrow e\gamma$ $b \rightarrow s$

Leptogenesis and low energy observables

Gustavo Branco

• Leptogenesis depends on all high-energy seesaw parameters: non-tivial dependence on the low-energy parameters

• Leptogenesis possible also if neutrino Dirac phase is zero

Possible ways to approach

1. Reduce free parameters by means of model building
2. Scan over the full parameter space, predict as many observables as possible and hope that they will be measured

Request for the theory of flavour

What is the origin of quark and lepton masses and mixings?

- Flavour models based on Abelian and non-Abelian flavour symmetries (Oscar Vives)

- Constraints on Yukawa interactions from GUT relations (Borut Bajc, Amon Ilakovac)

U(1) and SU(3) flavour models

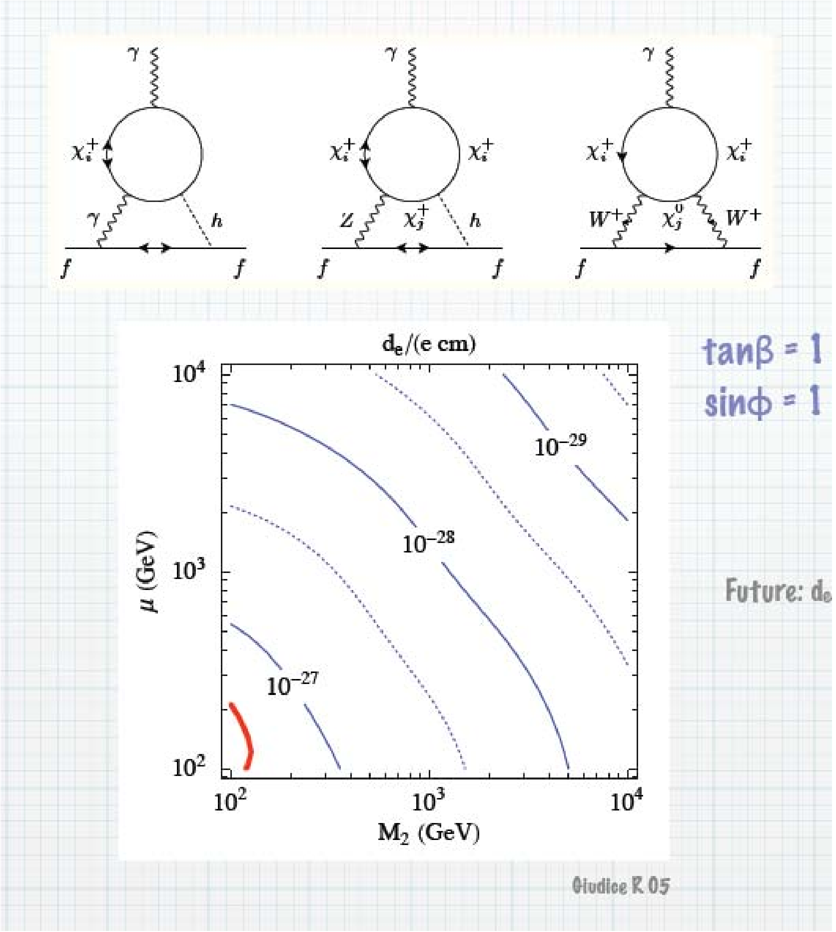
- Two concrete examples of flavour models
- Flavour symmetries are broken also in the SUSY sector inducing left-slepton δ_{LL} and right-down-squark δ_{RR}
- Observable LFV processes and large $b \to s$ transition

MSSM based on SO(10)

- Minimal Higgs content $10_H + 126_H$
- Predicts b-τ unification and large θ_{atm}
- Amon Ilakovac: observable BR($\mu \to e\gamma$)
- Borut Bajc: if 126_H is missing, M_N can be generated at two loop in split SUSY model

$$M_N \propto m_{SUSY}$$

Andrea Romanino: In split SUSY EDMs are still observable



Predictive neutrino mass model

Amarjit Soni: a model in which t-quark and N_3 couple to the different Higgs doublet than all other fermions

- **Predictions (with normal hierarchy $m_3 >> m_2 >> m_1$):**
  - **a triple t - ν - N seesaw connection:**
  - $-0.02 < \theta_{13} < 0.02$ (3σ)
  - $43^0 < \theta_{atm} < 45^0$ (3σ)
  - $28^0 < \theta_{sol} < 36^0$ (3σ)
  - $M_{N1} << M_{N2} << M_{N3}$

$$m_{\nu_3} \approx \frac{m_t^2}{M_{N_3}}$$

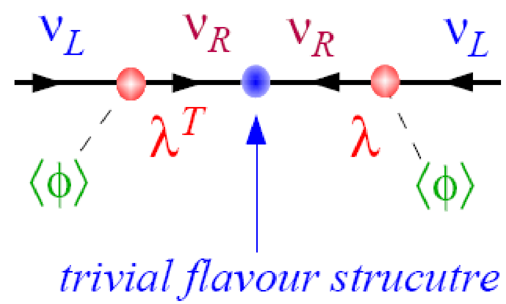
Minimal LFV

Gino Isidori: Consistent way to reduce free parameters from low energy point of view

$$\frac{1}{\Lambda_{LN}} (L_L^T)^i \, g_\nu^{ik} L_L^k \, \phi^T \phi$$

irreducible — reducible [see-saw type]

$$g_\nu \sim \lambda^T \lambda$$



Triplet Higgs coupling

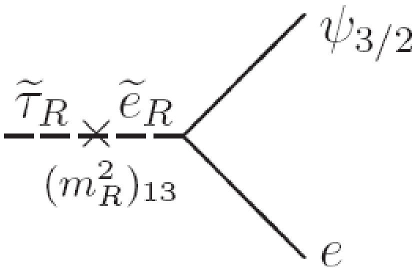
Heavy neutrino seesaw

$H^{++} \to \mu^+\mu^+, \mu^+\tau^+, \tau^+\tau^+$

Background free at LHC

LFV in SUSY particle decays at colliders (I)

- Alejandro Ibarra: gravitino LSP, stau NLSP

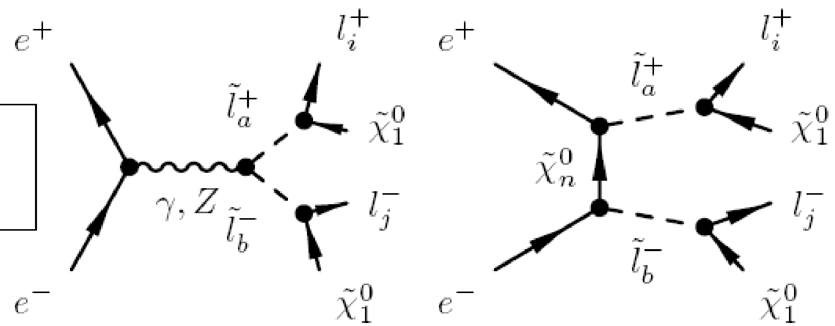


- LFV at LC can be probed down to $(m^2_{\widetilde{l}_R})_{13}/m^2_1 \lesssim 3 \times 10^{-2}$
  work for LHC in progress
- Collider experiments probe LFV directly, complementary to rare decays

LFV in SUSY particle decays at colliders (II)

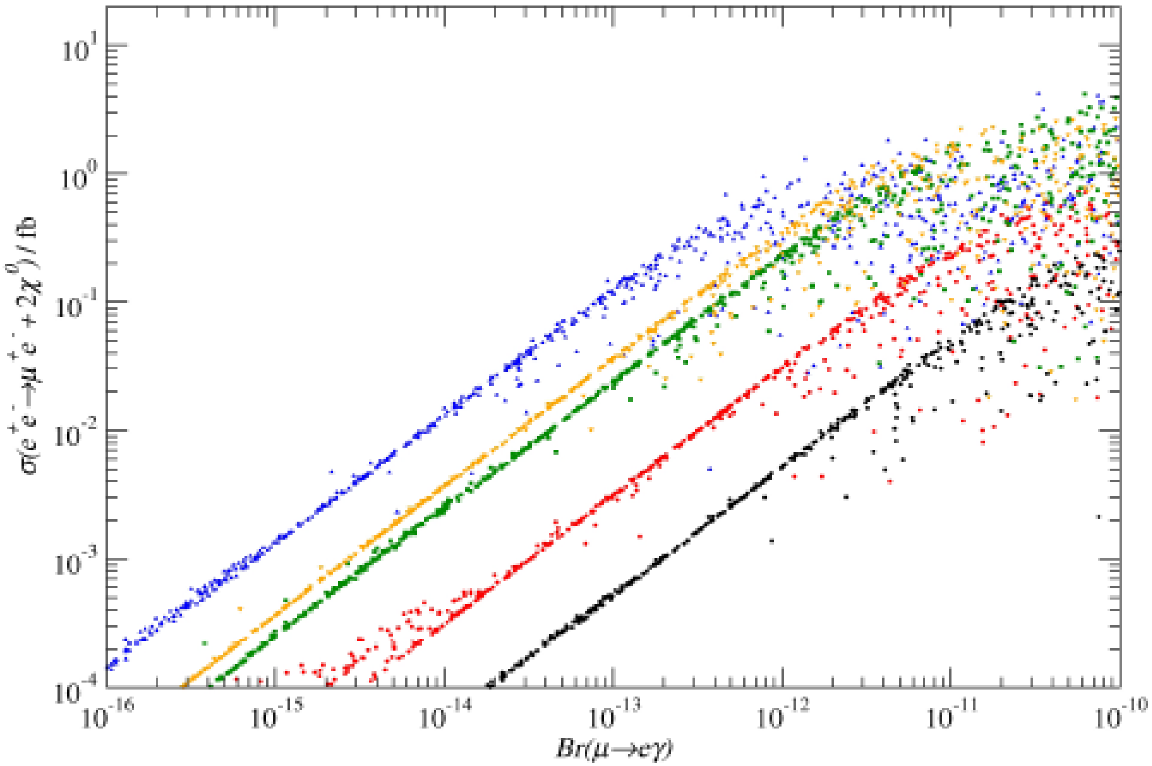
- Reinhold Rückl: M_N degenerate, R real

$$e^+e^- \to l_i^+ l_j^- + 2\tilde{\chi}_1^0$$



SUSY points C', G', B', SPS1a, I'

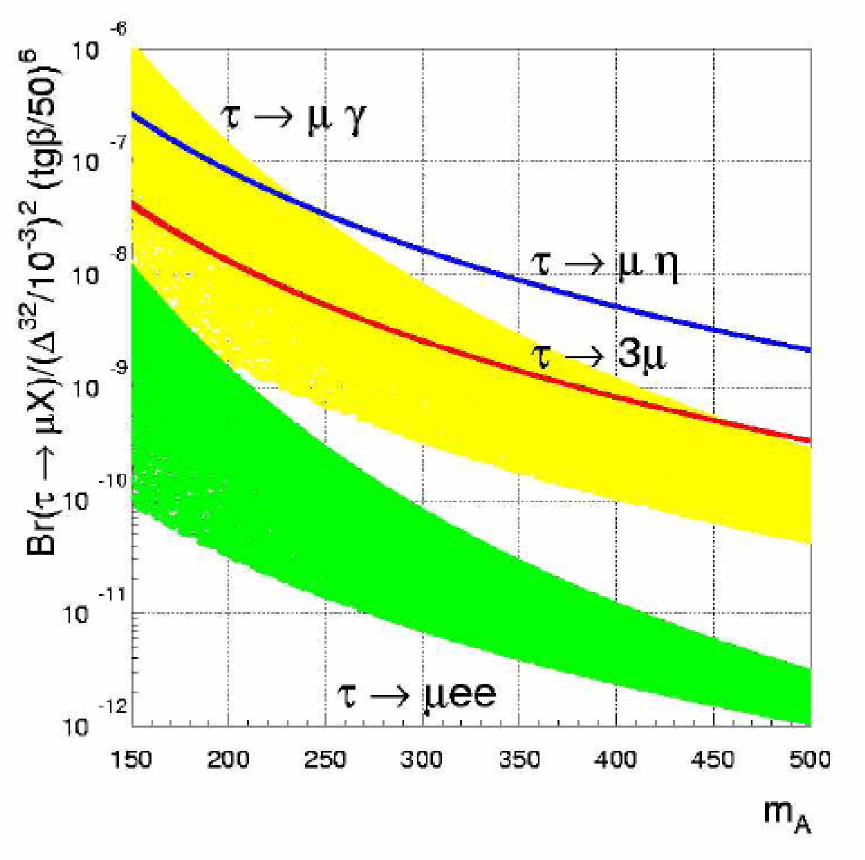
$\sqrt{s} = 800$ GeV



$Br(\mu \to e\gamma) > 10^{-12}$ implies $\sigma(e^+e^- \to \mu e + 2\tilde{\chi}^0_1) > 0.01$ to 1 fb

Higgs mediated LFV

Paride Paradisi: MSSM + non-holomorphic soft terms



R-parity violation

- Aldo Deandrea: review on possible collider signatures of R-parity violating couplings

$$W_{\not R_p} = \mu_i H_u L_i + \frac{1}{2} \lambda_{ijk} L_i L_j E^c_k + \lambda'_{ijk} L_i Q_j D^c_k + \frac{1}{2} \lambda''_{ijk} U^c_i D^c_j D^c_k$$

48 par.

$$V^{soft}_{\not R_p} = \frac{1}{2} A_{ijk} \tilde{L}_i \tilde{L}_j \tilde{l}^c_k + A'_{ijk} \tilde{L}_i \tilde{Q}_j \tilde{d}^c_k + \frac{1}{2} A''_{ijk} \tilde{u}^c_i \tilde{d}^c_j \tilde{d}^c_k + B_i h_u \tilde{L}_i + \widetilde{m}^2_{di} h^\dagger_d \tilde{L}_i + \text{h.c.}\,.$$

51 parameters

Couplings of the order of 10^{-1}-10^{-2}, could lead to observable effects at high energy colliders

CPV effects in tau decays

- Zbignev Was: discussed CP effects in TAUOLA Monte Carlo generator for τ decays and tau production processes.

- Tools made available for CLEO, LC, BaBar/Belle and LHC communities

Outlook

- Identify benchmark models for consistent analyses of LFV at colliders and in rare decays (WG1+WG2+WG3)
- Extend LFV studies for LC to LHC (WG1+WG3)
- Applications of Minimal LFV concept
- Connections between soft leptogenesis and EDMs
- T-odd asymmetries in tau->3l, mu->3e decays